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Final Engineering Report Phase I HYCOS (Hydraulic Check Out System)

Grumman Aerospace Corp Bethpage N Y

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FINAL ENGINEERING REPORT - PHASE I
HYCOS (HYDRAULIC CHECK OUT SYSTEM)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This six months study effort investigated the normal and abnormal operating parameters of critical for flight components found in a typical sophisticated airborne hydraulic system. The basis for this investigation was to establish the ground rules necessary to develop monitoring criteria for components used within the system. Normal operating parameters were defined and proposed limits established with respect to components, subsystem and systems. (con't.)

Components considered suitable for monitoring included reservoirs, pumps, accumulators, pneumatic bottles, shock struts, flight control actuators, desiccants, relief valves and other components.

Fluid processing to determine particulate matter, water and chlorine could not be readily detected within the system however consideration was given to provide sampling ports at strategic locations within the system without the addition of sampling valves.

Remote sensors could be readily added to some components while other specific sensors were required to monitor specific sub-system conditions.

A simple small ground accessable display panel utilizing principally light emitting diodes evolved. The panel has a test circuit and an interrogate circuit. In some modes system hydraulic and electric power is required to determine system conditions. Recommendations were made for further system integration and effort.

FOREWORD

This study was conducted by the Grumman Aerospace Corporation, Mechanical Design Section, A. T. Barbero, Section Chief, under U. S. Navy Contract Number N62269-76-C-0195.

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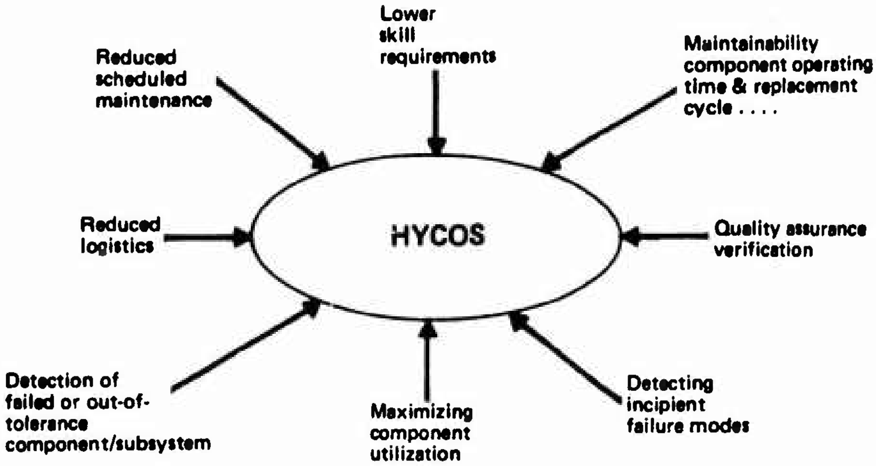


Expected benefits of HYCOS

SUMMARY

This study effort investigated normal and abnormal operating parameters of critical-for-flight components found in a typical sophisticated airborne hydraulic system. The basis for this investigation was to establish the gound rules necessary to develop monitoring criteria for components used within the system.

Vehicles used as part of the study were: the A-6E, Intruder, F-14A Tomcat, EA-6B Prowler, and E-2C Hawkeye.

Normal operating parameters were defined and proposed limits established with respect to components, subsystem and systems. Data was obtained from available design reports or was determined empirically.

Components considered suitable for monitoring included: reserviors, pumps, accumulators, pneumatic bottles, shock struts, flight control actuators, desiccants, relief valves, filters and others.

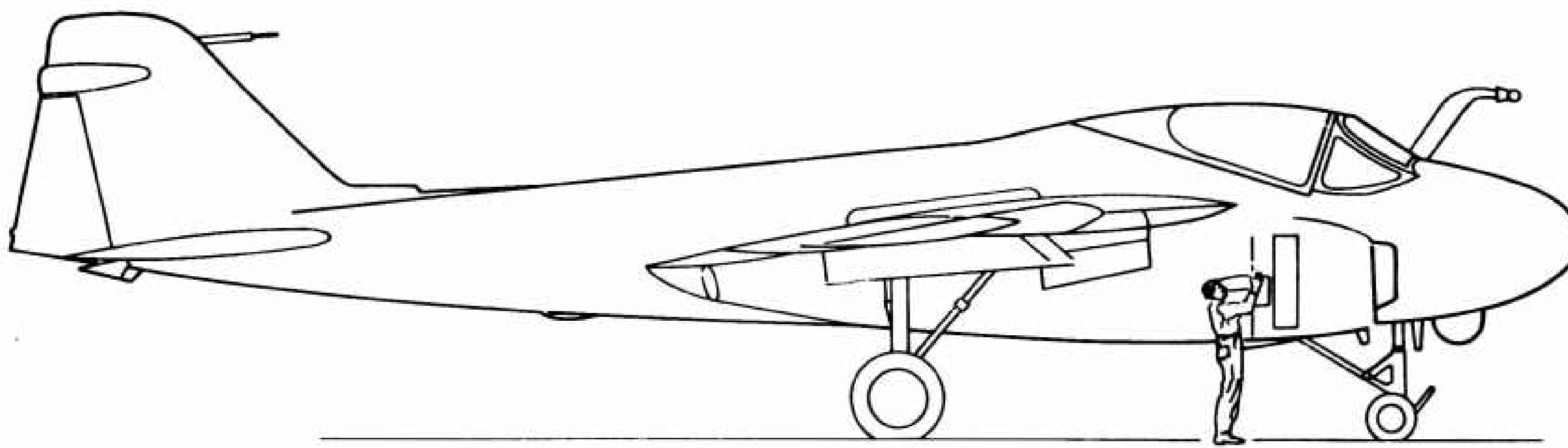
Fluid processing to determine particulate content, water and chlorine could not be readily detected within the system, however consideration was given to provide sampling ports at strategic locations within the system without addition of sampling valves. This is accomplished by combining the functions of two or possibly three components into one.

Fiber optics are utilized for color transmission from desiccators (saturation) liquid detection in pneumatic bottles, and possibly fluid level determination in shock struts. Two types of fiber optic materials were investigated. Minimum bend radius and repair methods were considered.

In areas where remote sensors could not be added to some compnents, subsystem modification was necessary to include these units.

A small simple ground accessable display model utilizing light emmitting diodes and fiber optics evolved. Two circuits (circuit test and system test) comprise the display panel. Circuit test verifies display integrity while system test verifies components subsystem and sensor integrity.

Recommendations were made for further system integration and effort.



HYCOS Access Location

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1-INTRODUCTION

The intent of HYCOS was to study an onboard ground readout hydraulic check out system. Usage of this system was directed primarily to maintenance personnel in an attempt to minimize down time and simplify system interrogation to a go/no go determination.

The system does not nullify the already apparent mechanical readouts which were initially in the system. In fact, it supplements them by providing an electrical readout at the display panel.

The second function HYCOS serves is as a quality assurance tool since the maintenance functions must be performed and/or the mechanical indicators reset before the display corrects itself. The display indication cannot be electronically reset.

Indication of a malfunction or out-of-limit conditions is by means of Light Emitting Diodes (LED). These versatile, low power demand units are used extensively on the readout panel. They only indicate during the test check and when the system test button is pressed.

2-TECHNICAL DISCUSSION

2.1 TYPICAL AIRCRAFT HYDRAULIC SYSTEM DESCRIPTION

The typical aircraft hydraulic system is designed in accordance with MIL-H-5440 and MIL-H-8775, which define the basic requirements. (Ref. 1&2)

Two completely independent 3000 psi closed loop Type I or Type II systems are used. The systems are not fluid interconnected although there may be power transfer from one system to another during emergency conditions.

Normally, both systems operate continuously through engine driven pumps with each system supplying partial power for operation of the primary flight control surfaces. Either system, however, is capable of operating the primary flight control surfaces should one system fail. Single or parallel variable delivery pressure-compensated hydraulic pumps are usually used on aircraft systems.

To illustrate the interface of a typical hydraulic system, a simple schematic block diagram is shown in Figures 1 and 2.

Hydraulic power generation is usually established at approximately 3000 psi for most systems. Pressure is generated by variable delivery pumps which compensate for system demand by increased pump piston stroking. With no system demand, the system pressure remains at 3000 psi and the pump only develops enough flow to compensate for system leakage.

When control inputs are fed to the flight control actuators (such as the rudder, stabilizer or flaperon) they respond in relation to the input signal. The actuator demand causes the pump to stroke in an attempt to maintain constant system pressure. The pump will usually maintain this pressure until the system demand exceeds the capability of the pump and storage devices, at which point system pressure will drop off until an energy equilibrium is reached.

To satisfy transient demands beyond the immediate capability of pump response, accumulators are sometimes used to handle momentary peak load requirements.

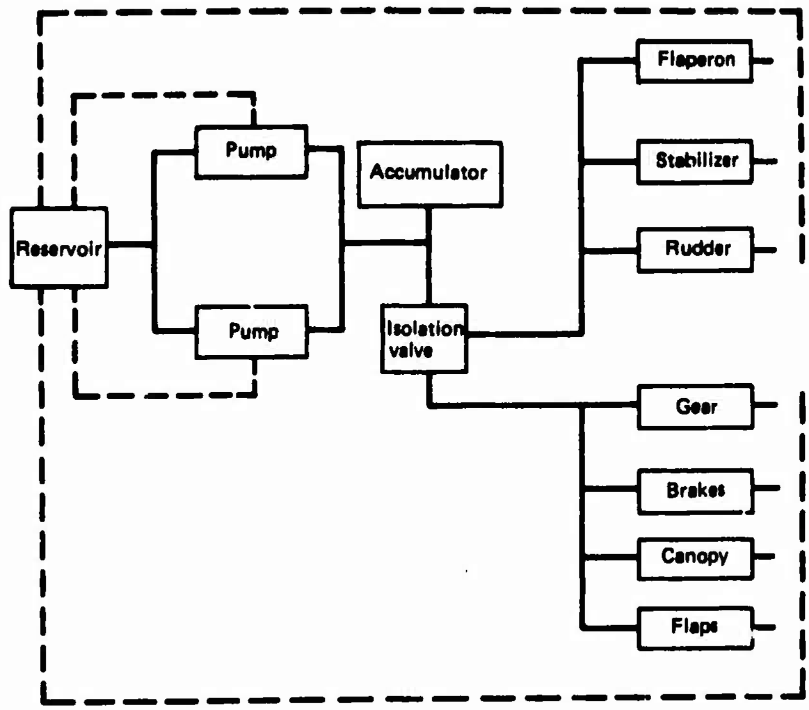


Figure 1. Combined system block diagram.

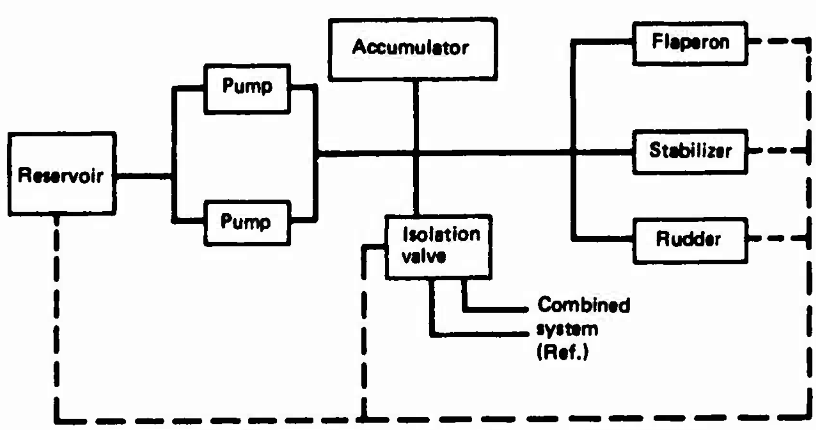


Figure 2. Flight system block diagram.

System pressure generating units are sized to handle peak demands during the entire flight spectrum. When the system has no demand there is an internal system leakage which is not utilized in aircraft operation. This system leakage can vary from

- 1.7% to 5.3% on A-6 attack aircraft
- 3.5% to 7.0% on F-14A fighter aircraft.

System leakage or quiescent flow is an indicator of system efficiency (E_S). System efficiency is dependent on the allowable system internal leakage of each component which is on the line during the various phases or modes of aircraft operation. When a component develops a potential of partial failure and that component cannot be isolated from the pressure source, the leakage through this component increases depending on the failure mode. Since the pump is pressure-compensated it automatically adjusts to the increased demand. By mere pressure gage observation, it would be impossible to determine this abnormal condition. Should the system leakage approach the pump capability, then momentary fluctuations in the system pressure gage would become evident during normal cockpit checkout.

2.1.1 Abnormal Operation

At idle condition (Figure 3) the pump is capable of handling normal leakage up to the pump capability limits at that speed. Should an abnormal condition exist, such as a major leak across a piston or shutoff valve, the quiescent flow would increase from the normal condition but the pump output would still be adequate at idle (Figure 4).

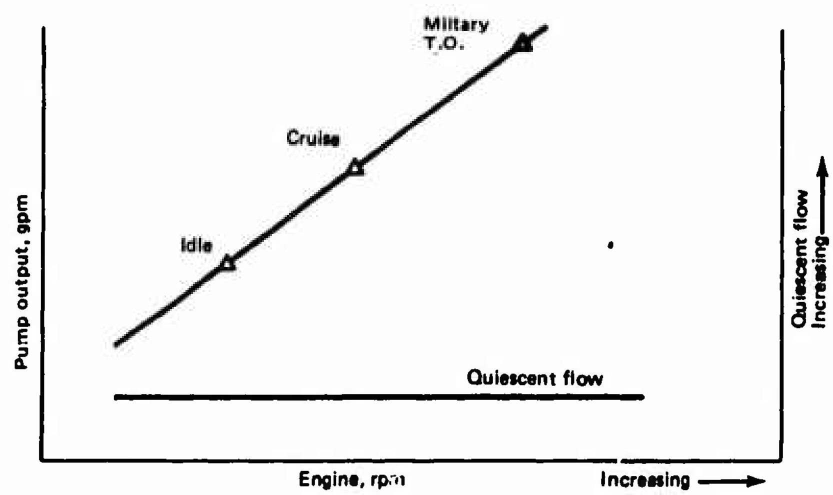


Figure 3. Hydraulic pump (normal operation).

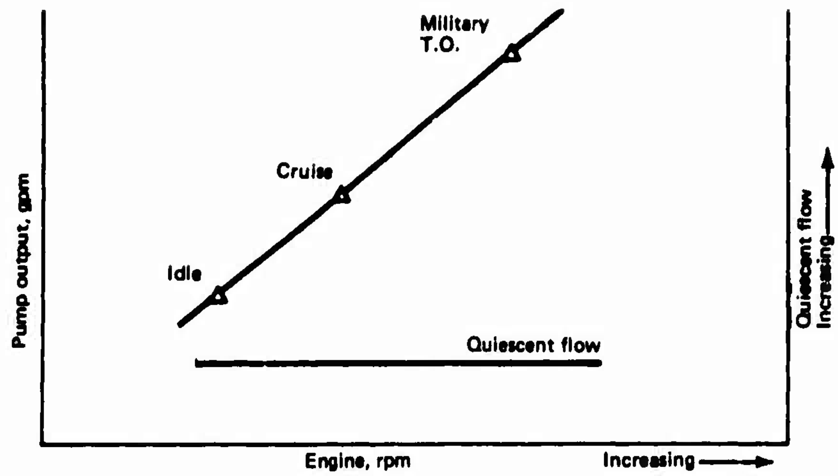


Figure 4. Hydraulic pump (abnormal operation).

2.1.2 Abnormal Operation with Major Internal Leak

Figure 5 shows that at idle the pump is not capable of maintaining full system pressure due to high internal system leakage. The resultant effect would be system pressure fluctuation or lower than normal system pressure. These curves represent conditions at idle with no system component demand.

It becomes evident that under conditions with no system demand it is possible to determine the relative health of the system independent of the initial design parameters and the number of components on the line at the time.

2.2 HYDRAULIC SYSTEM OPERATING PARAMETERS AND MONITORING CRITERIA

Normal and abnormal operating parameters of critical-for-flight components must first be established in order to properly design a hydraulic check out system.

Normal conditions are defined as those for which the system was designed over its useful operating pressures, temperature and flow ranges. When limits exceed maximum allowable values, they indicate that the component or subsystem is operating beyond its norm. In the majority of instances, this indication can point to a degradation of system performance and/or total system failure. The selection of out-of-limit conditions is an important and crucial one which is derived from theoretical and empirical data on that particular component or subsystem. In some cases more than one parameter exceeds its previously defined limits indicating that a specific failure mode is in process.

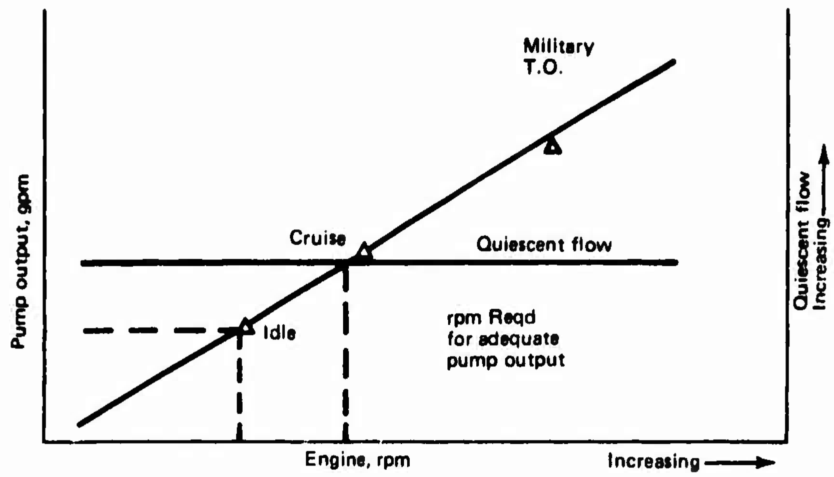


Figure 5. Hydraulic pump (abnormal operation with leak).

Individual failure modes can sometimes relate to a degraded system operation that does not directly affect flight safety or mission completion. Fluid power systems may be broken down into three major categories:

- Power Generation
  - Engine driven pumps
  - Electric motor driven pumps
  - Transfer pumps.
- Power Processing and Transmission
  - Reservoirs
  - Valves
  - Filters
  - Accumulators
- Fluid condition determination
  - Water
  - Particulate Matter
  - Chlorine
- Relief valve fluid flow temperature
- Actuators
- Miscellaneous
  - Pneumatic bottle pressure
  - Gear strut pressure

- Dessicant saturation
- Over-temperature, back-up package
- Over-temperature, spoiler and high lift package
- Water/oil detection in pneumatic bottles
- Elapsed-time meters.

Table 1 shows some of the major system operating parameters and those variables which affect performance. They are general in nature and will be covered in more detail later in the report. Table 2 depicts the principal methods investigated in the sensor area. This is by no means complete.

Four Grumman aircraft in production were selected to determine which components were suitable for "HYCOS" monitoring. Since the vehicles differ somewhat in design approach and time period there is a small disparity between the various systems. 'Table 3 shows this compilation. In addition, the basic study investigated each specific aircraft system and components in an effort to determine current operating limits in those areas previously covered and recommended suitable for monitoring. Table 4 shows this listing.

2.3 COMPONENTS MONITORED

2.3.1 Pumps

A hydraulic pump is perhaps one of the most important components in a hydraulic system and as such, its condition should be carefully monitored. One way of accomplishing this is by noting it's case drain flow. Increased pump case flow is an indication of pump degradation and reduction of overall efficiency. Case flow conditions at idle are usually higher than those at full flow condition. Therefore, no flow or low flow conditions can be used to determine pump degradation as a function of pump operating time. Figure 6 shows a typical variation of hydraulic pump case flow versus pump life hours at various system demands. Since the no flow condition could only be obtained by completely blocking the pump outlet port (0 discharge flow) the actual case flow will follow a representative line in the vicinity of the no flow curve (extrapolated).

TABLE 1. SYSTEM OPERATING PARAMETERS

Pumps	Discharge & case flow Case fluid temperature Discharge pressure Case fluid debris
Flight controls	Quiescent flow Differential displacement
Reservoir	Level, fluid temperature Air, pressure
Filters	Differential pressure Flow, temperature
Fluid condition	Cleanliness level, water, Chlorine
Landing gear struts	Pressure, level
System relief valve	Temperature
Accumulator	Pneumatic precharge Piston displacement
System	Quiescent flow, elapsed time
Pneumatic	Pressure, temperature

TABLE 2. AREAS OF SENSOR INVESTIGATION

Pressure	Pressure switches Pressure switches, temperature compensated Pressure transducers Pressures differential, switches
Temperature	Thermal switches Thermal transducers
Flow	Quiescent • Orifice • Venturi
Level	Potentiometer Limit switches Hall effect sensors Fiber optics Capacitance
Differential displacement	Potentiometer • Linear • Rotary
Dessicant saturation	Color
Fluids	Sampling valves

TABLE 3. SYSTEM COMPONENTS SUITABLE FOR MONITORING

Code		A-6E	F-14	E-2C	EA-6B
	○ Hydraulic Reservoirs				
L&T	– Air oil	•		•	
L&T	– Bootstrap		•		•
L	– Backup System	•	•		
	○ Filters				
P&ΔP	– Pressure	•	•	•	•
P&ΔP	– Return	•	•	•	•
P, ΔP&T	– Pump case drain	•	•	•	•
	○ Accumulators				
PC	– Brake	•	•	•	•
PC	– Ram air turbine	•			•
PC	– Canopy		•		
PC	– Main System	•	•	•	•
	○ Pneumatic Bottles				
P	– Canopy	•	•		•
P	– Landing gear	•	•	•	•
P	– Door	•	•	•	•
P	– Tail Hook (Dashpot)	•	•	•	•
	○ Shock struts				
PC&L	– Nose Gear	•	•	•	•
PC&L	– Main Gear	•	•	•	•
	○ Hydraulic pumps				
F&T	– Case drain (flow)	•	•	•	•
QF	– Pressure, flow (quiescent)	•	•	•	•
P	– Inlet (Pressure)	•	•	•	•
	○ Flight controls				
D.D.&QF	– Rudder actuator	•	•*	•	•
D.D.&QF	– Stabilizer Actuator	•	•*	•	•
D.D.&QF	– Flaperon actuator	•	•*	•	•
D.D.	– Control column	•		•	•
	○ Pneumatic dessicant				
S.	– Moisture (saturation)	•		•	
	○ Hydraulic backup package				
T	– Over Temperature		•		
	○ Spoiler system & highlift backup package				
T	– Over temperature		•		
	○ Elapsed time meter				
H.	– System operational hours	•	•	•	•
	– Flight Duration	•	•	•	•
	○ Fluid sampling				
FS	– Particulate matter (cleanliness level)	•	•	•	•
	– Water	•	•	•	•
	– Chlorine content	•	•	•	•
	○ Pneumatic bottles				
M	– Liquid Content	•	•	•	•
	○ Relief valve				
N	– Over temperature	•	•	•	•

Legend

L	Indicates level	DD	Indicates differential displacement
P	Indicates pressure	S	Indicates mositure saturation
ΔP	Indicates differential pressure	T	Indicates over temperature
PC	Indicates precharge pressure	H	Indicates hours & tenths
F	Indicates flow	M	Indicates mixture H_2O/oil in pneumatic bottles
QF	Indicates quiescent flow	FS	Indicates fluid sampling
		*	QF only

TABLE 4. SYSTEM COMPONENT LIMITS

	A-6	EA-6B	E-2C	F-14
Accumulator, precharge, psi ● Normal ● Abnormal	Flight Combined 2000±50 2000±50	Flight Combined 2000±50 2000±50	Flt Combined Brake 2000 2000 800	Flt Combined Brake 1800 1800 950 <1700 <1700 >1900 >1900
● Normal ● Abnormal	Brake RAT 800±50 500±50	Brake RAT 800±50 500±50		Bootstrap 1800
Pneumatic bottle, psi ● Normal at 70°F ● Abnormal	Landing gear Canopy 2450 2450	Aux Canopy Canopy 3000 3000	L.G. L.G 3000 3000	Aux Canopy Canopy L.G. 3000 3000 3000 <1000 <500 <2000
Fluid condition cleanliness level ● Normal ● Abnormal				Navy CL5, NAS 1638 CL8 >than above
Water content, ppm ● Normal ● Abnormal	<300 >300	<300 >300	<300 >300	100 200 PPM by vol 7200 PPM by vol
Chlorine content, ppm ● Normal ● Normal ● Abnormal P/H Number ● Normal ● Abnormal	non-specified	non-specified	non-specified	non-specified
Quiescent flow system, gpm ● Normal ● Abnormal	0.5 - 1.5	0.5 1.5	unknown unknown	Combined flight up to 8% up to 4% rated flow rated pump flow >10% >8%
Relief valve (main, psi) ● Normal ● Abnormal	3560 3560	3560 3560	3785 at 32 gpm 3560 psi	3750 at 84 gpm
Main gear strut ● Normal ● Abnormal	pressure level	pressure level	pressure level 1125 psi	pressure level 979 psi ±15% Normal
Nose gear strut ● Normal	pressure level 350 psi	pressure level	pressure level 500 psi	pressure level 1300 psi ± 15% Normal
Pressure System, psi ● Normal ● Abnormal	3000 Below 2250	3000 Below 2250	3000 Below 2250	3000 3100 3200
Temp system (°F), reservoir ● Normal ● Abnormal	Flight Combined <187 <190 >187 >190	Flight Combined <187 <190 >187 >190	Flight Combined <206 F <208 F >206 F >208 F	-65 F to 275 F >275°F
Pump – case flow, gpm ● Normal ● Abnormal			Flight Combined 1.3	2.5 3.5 >4 gpm
Case flow fluid temp, °F ● Normal ● Abnormal	Flight Combined 225 263 225 263	225 263 225 263	244 max 244	275 ± 10 F 290 F
Filters, Δ psi ● Normal ● Abnormal	<70 ± 10 >80	<70 ± 10 >80	<70 ± 10 >80	70 ± 10 >80
Reservoir – ● Level – normal abnormal ● Pressure – normal, psi abnormal	Flight Combined 0.97 gal 4½ gal 40 ± 1 >45 >35	Flight Combined 0.74 gal 3.34 gal 0.61 gal 3.00 gal 39 41.5 50.7	Flight Combined 1.255 2.57 1.063 2.23 40 psi >45 psi	Flight Combined 105 105
Moisture, desiccant ● Normal ● Abnormal	No indicator (saturated)	None	No indicator, replace, dryer every 75 flight hrs	None

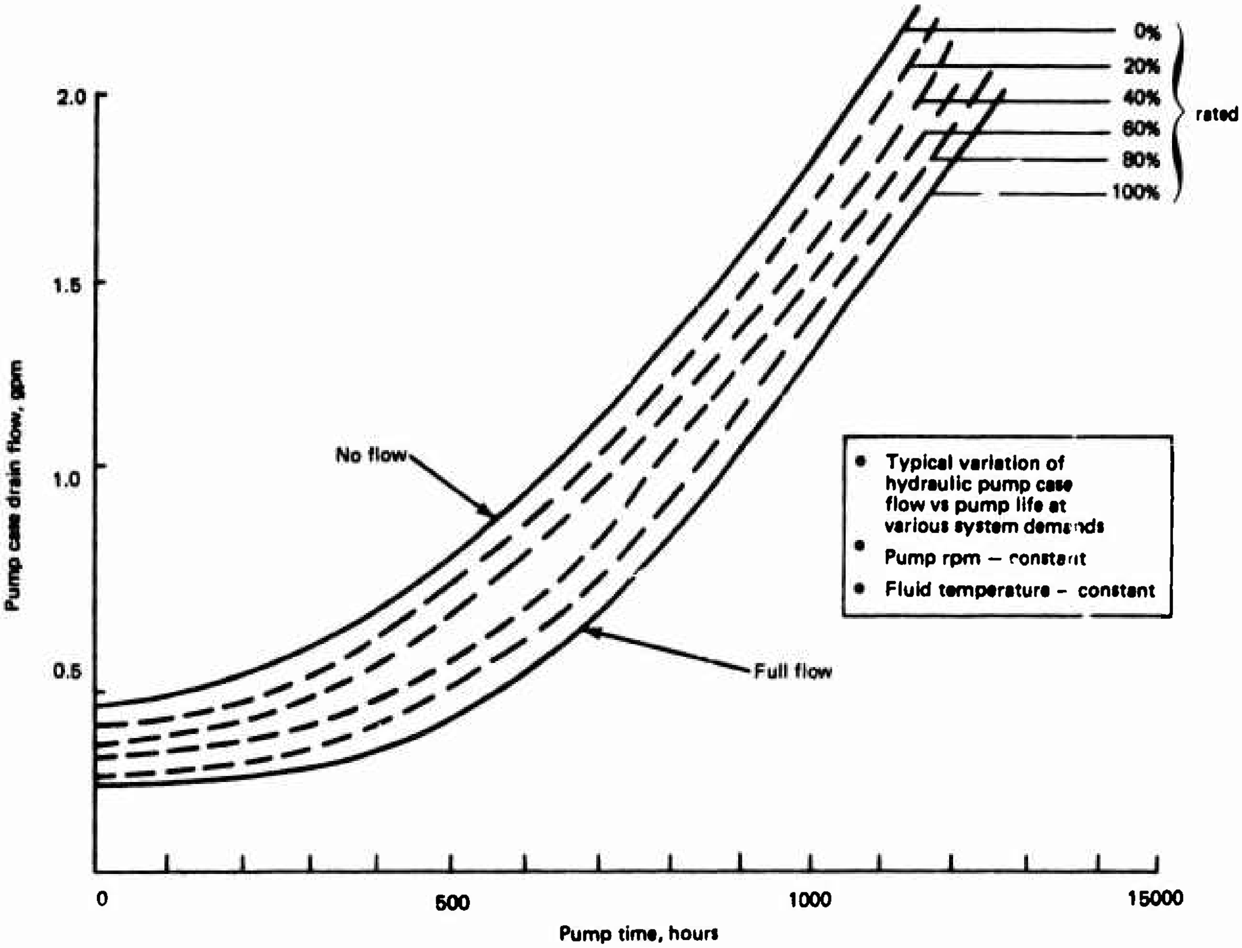


Figure 6. Pump case flow vs life.

For example, at 1000 hours, the pump case flow varies between 1.7 and 1.8 gpm depending on the pump discharge flow at no demand conditions. Assuming the quiescent leakage is maximum, which is approximately 43% of the output, the pump case flow would be in the vicinity of 1.06 gpm after 1000 hours.

Two additional case drain flow curves are shown. The values are plotted against discharge flow. It becomes evident that the shape of the curves differ. What is of interest is the maximum value achieved. Figure 7 shows the variation of an E-2C combined hydraulic pump. For the F-14 hydraulic pump the case drain flow actually decreases as the discharge flow increases. See Figure 8.

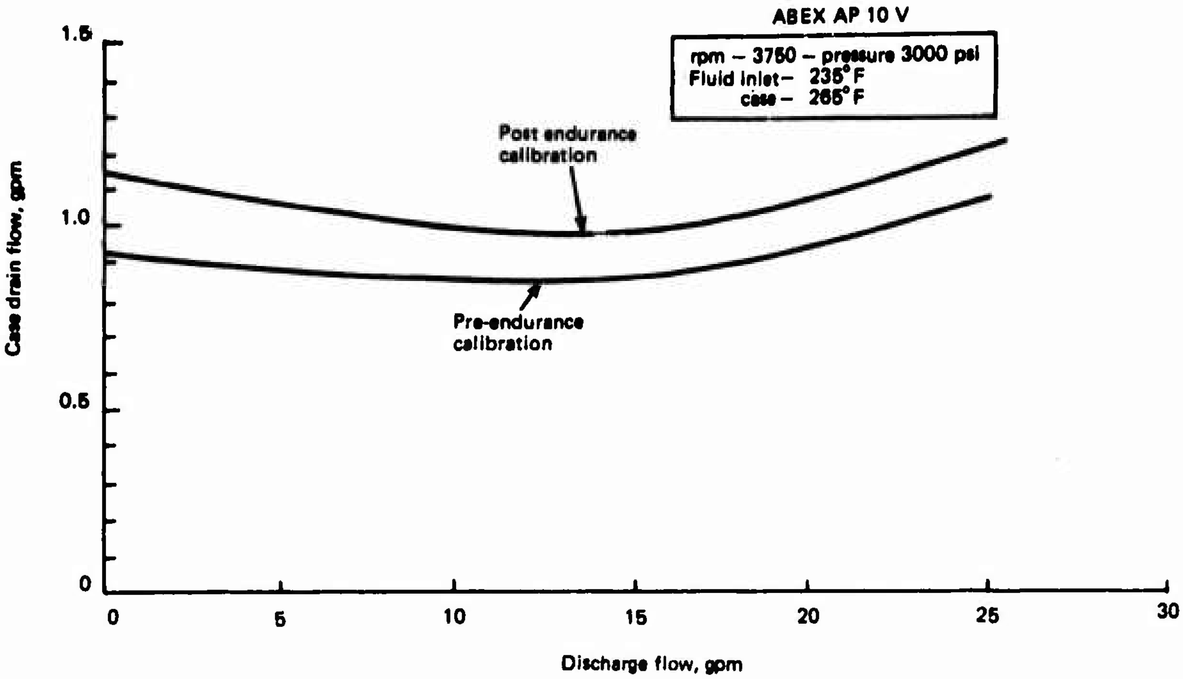


Figure 7. Pump case flow vs discharge flow (25 gpm).

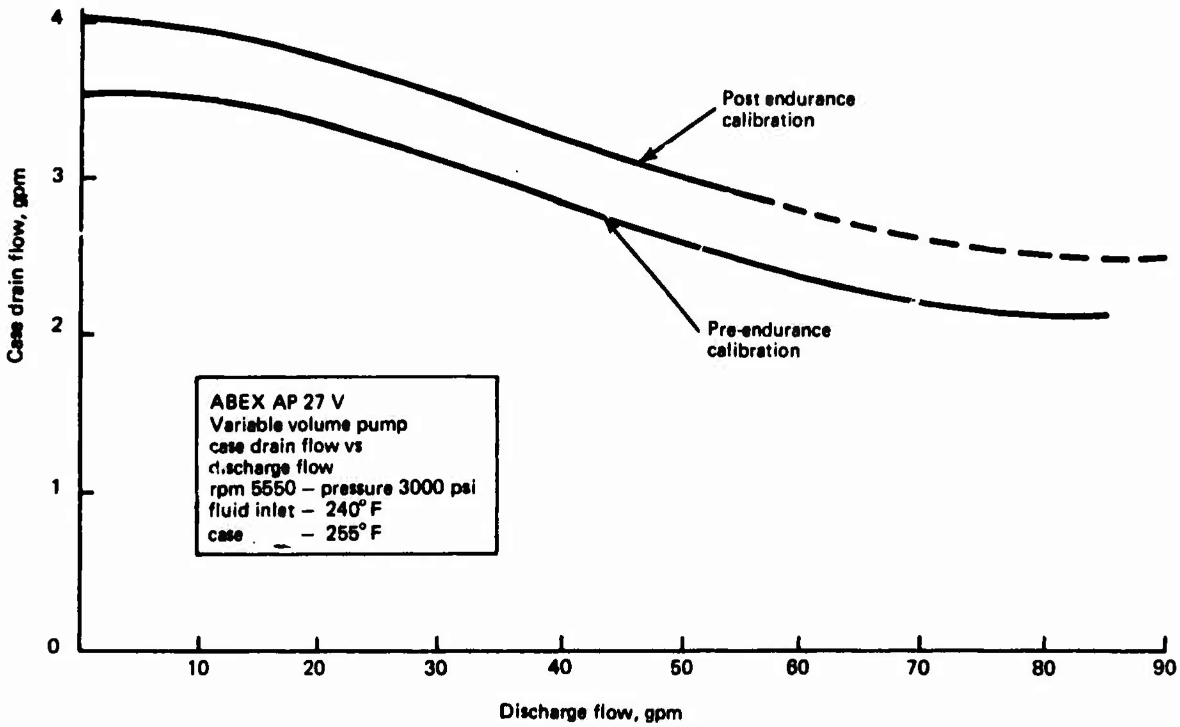


Figure 8. Pump case flow vs discharge flow (84 gpm).

2.3.2 Hydraulic Line Filters

In order to protect components within the hydraulic system, filter requirements are specified by MIL-H-5440. For Naval aircraft, 5 micron disposable units per MIL-F-8815 are utilized. (Ref. 3) These disposable units are of the high differential (3000 psid collapse) type which are used in both the pressure and return portions of the hydraulic circuit. These filters, when properly installed, tend to keep the system fluid cleanliness level better than Class 4 of NAS 1638.

As a minimum, non-bypass line type filters are installed in the pressure line so that all the fluid from the aircraft pump and ground test equipment is filtered before reaching any major component. Return the line filters, with bypass valves are used to filter all the fluid entering the return circuit prior to entering the pump suction line and reservior. Pump case drain filters are used to filter pump internal leakage prior to entering the reservoir.

Current practice usually sizes the filters on the basis of average fluid velocity rather than debris generating characteristics of the components and circuits. The filters contain differential pressure indicators which indicate partially clogged units at various points in the system. These indicators are temperature sensitive and unlock at $35 \pm 15^{\circ}F$, $100 \pm 15^{\circ}F$, or some other specified setting depending on system design objectives.

This temperature lock-out compensates in part for the viscous fluid changes and prevents inadvertent indicator operation due to low initial fluid temperatures. As the system warms up, the fluid temperature increases and the viscosity decreases resulting in a pressure drop reduction at constant flow. Figure 9 shows viscosity change of MIL-H-5606 versus temperature. Figure 10 shows the effect of differential pressure at constant flow with varying temperature conditions.

Under normal conditions hydraulic system filters have a rather substantial service life, i.e., they can run for 300 to 500 flight hours without requiring replacement. They are designed to handle normal system contaminant generation without difficulty. In cases where abnormal conditions exist like pump breakdown, the filters usually load up rather quickly during the degradation mode of the component. For example, if a pump is deteriorating rapidly, the case drain line filter pressure-drop will build up very quickly but only when the indicator button actuates will you have any indication of problems in that circuit. There is usually no prior warning that a deteriorating pump condition exists.

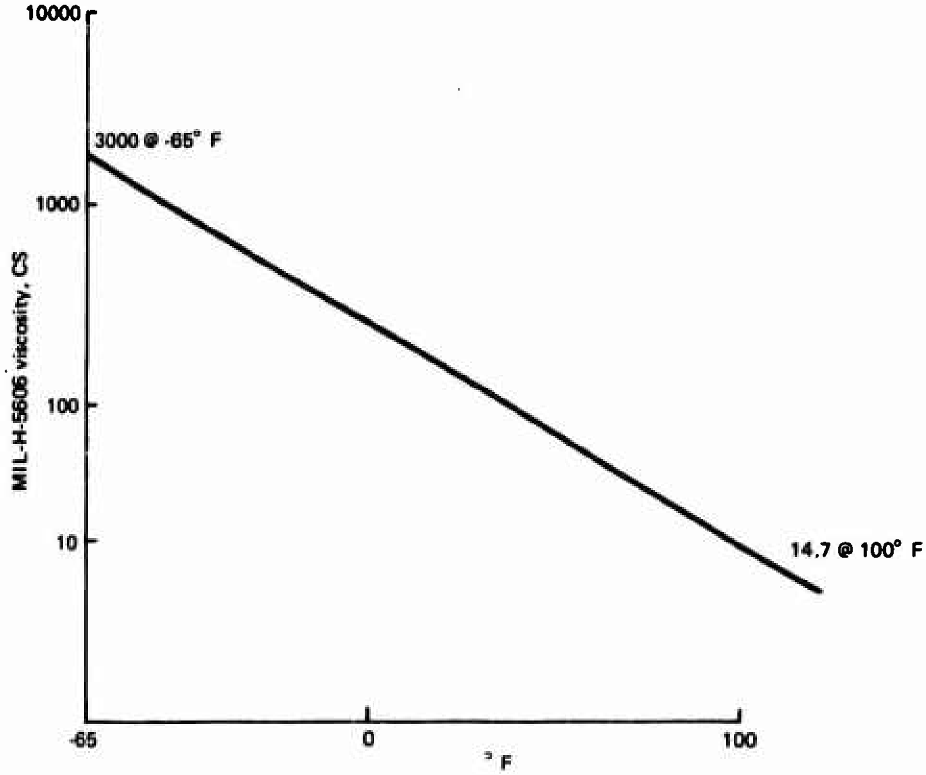


Figure 9. Viscosity vs temperature (MIL-H-5606).

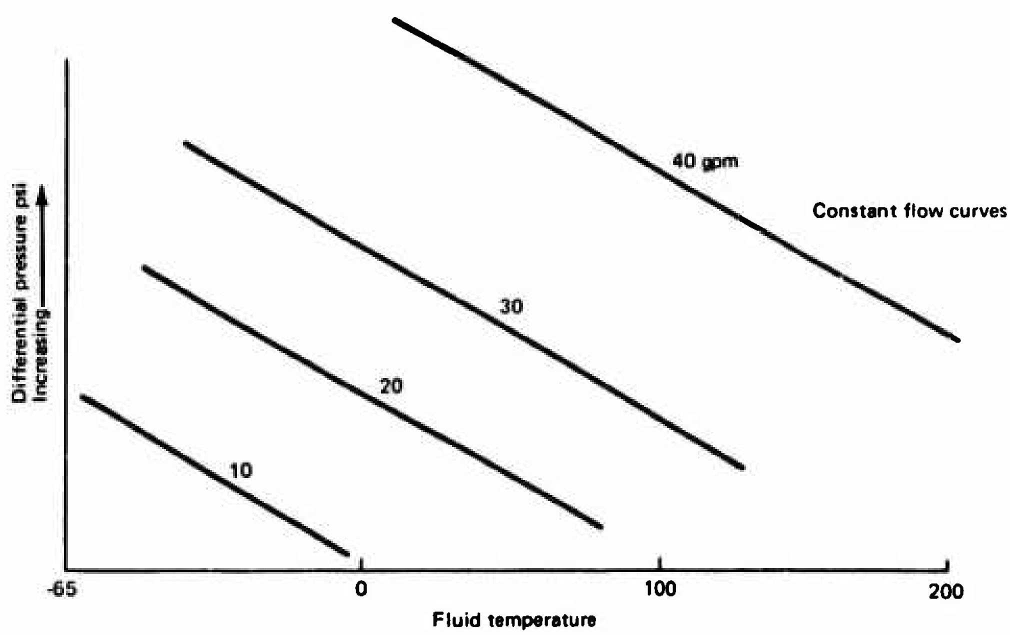


Figure 10. Filter differential vs temperature at constant flow.

Recent design trends tend to consolidate components (including filters) into modular packages, resulting in significant volume and weight savings. This approach is more conducive to monitoring critical sensing parameters. For example, the differential pressure indicator port provides a potential tap for:

- Remote electrical readout
- Fluid temperature
- System pressure variations
- Filter element differential pressure buildup
- System fluid cleanliness level.

In order to effectively monitor system integrity it is desirable to measure contaminant rate buildup taking into account temperature and flow variations. One area where this may be done is in the pump case drain line where the flow ranges are not as high as found in the pressure and return portions of the circuit. In order to measure rate, it is necessary to include some time base.

i.e., $\frac{\Delta P}{\Delta c} = f\ (Q)\ \&\ (T)$

where:

$\frac{\Delta P}{\Delta c}$ = rate of change

Q = flow

T = temperature

c = contaminant buildup

During normal contaminant buildup, the case drain filter $\Delta P/\ c$ is very low. In abnormal conditions the rate would change. While it is known that the ΔP curve is not linear for most filter media, compensation or allowances can be made for changes in slope under constant flow conditions.

The effect of temperature on dirt holding capacity is shown in Figure 11. It is desirable to select a thermal ΔP unlock condition as high as possible after considering the minimum subsystem operating condition.

In Figure 12 we see that the ideal contaminant curve starts from an initial clean pressure-drop and then builds up to terminal point where a visual Δp indication is observed.

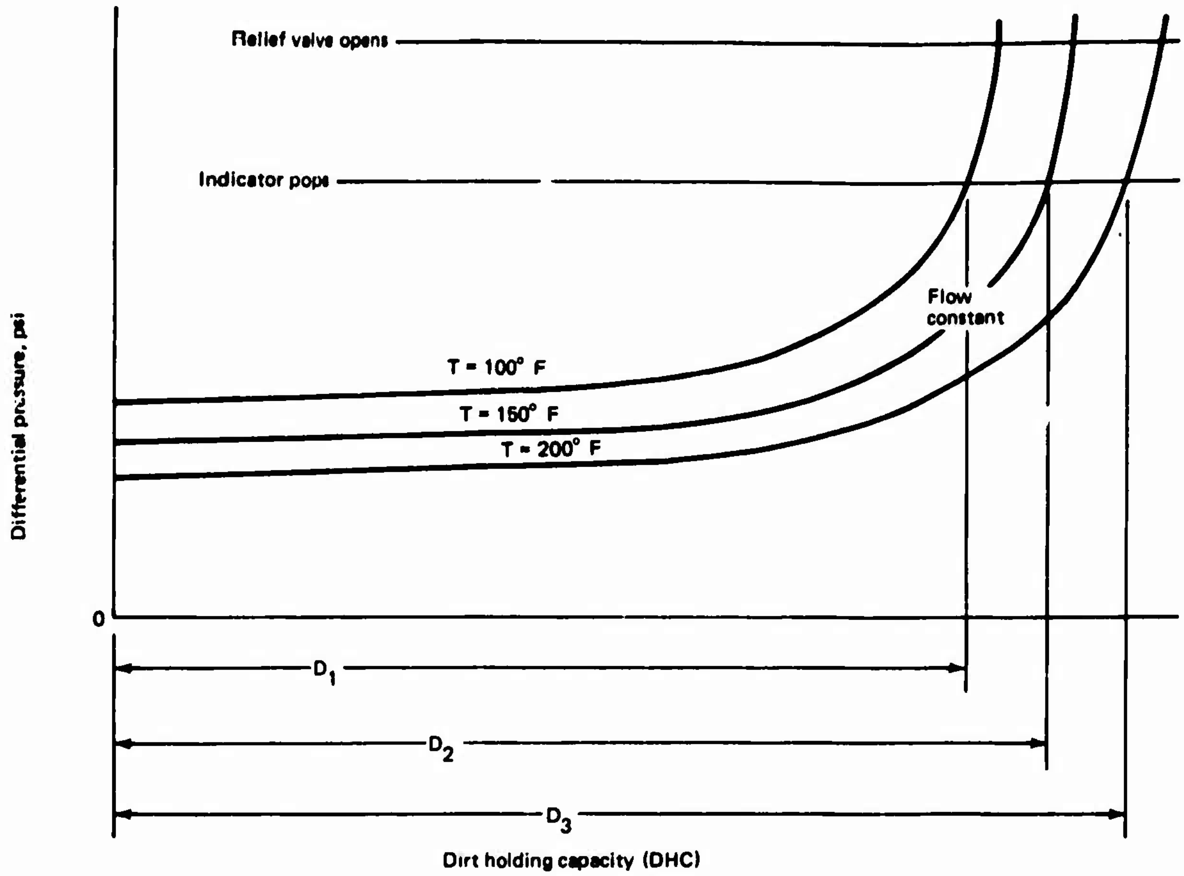


Figure 11. Dirt holding curve as affected by temperature.

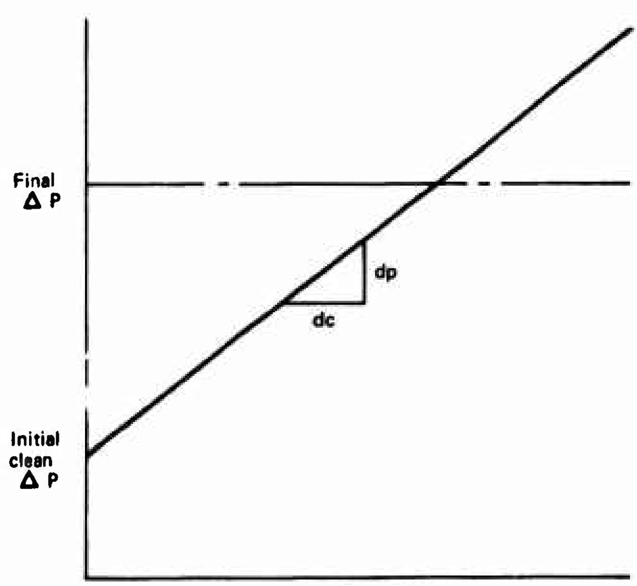


Figure 12. Ideal DHC curve.

If Δp is plotted against unit time then it is possible to measure dp/dc as the slope changes. With current filters this is not readily put to practice due to the construction and buildup characteristics of the filter element (See Figure 13). If a filter element were made as a constant Δp device, then a means of detecting incremental contaminant buildup could be more readily accomplished.

Another possible method is to utilize fiber optics to monitor pump case flow and transmit an LED light to a densitometer type unit which is calibrated against a time base. At a predetermined value the LED would illuminate before Δp button would actuate, indicating an abnormal contaminant rate buildup. This approach may be suitable for the pump case drain line since case flow does not vary appreciably as does the pressure or return line.

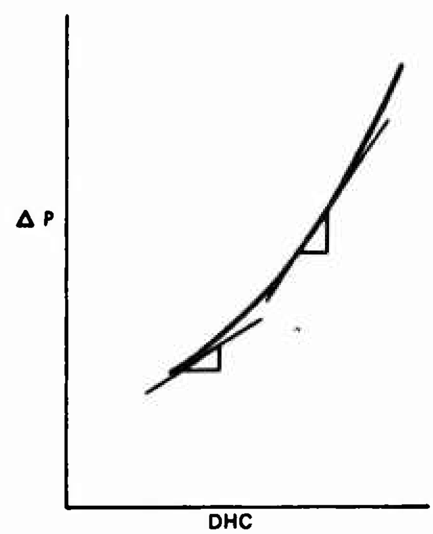


Figure 13. Actual DHC curve.

2.3.3 Reservoir Level Sensing

Reservoirs designed in accordance to MIL-R-8931 used in modern aircraft hydraulic systems can be categorized into two basic types. (Ref.5)

- Pneumatic pressurization
- Bootstrap pressurization.

Pneumatic pressurization (Figure 14), relies on compressed, regulated air or nitrogen acting on a diaphragm or piston. Reservoir pressurization is designed primarily to prevent pump cavitation during system demand transients which can be disasterous.

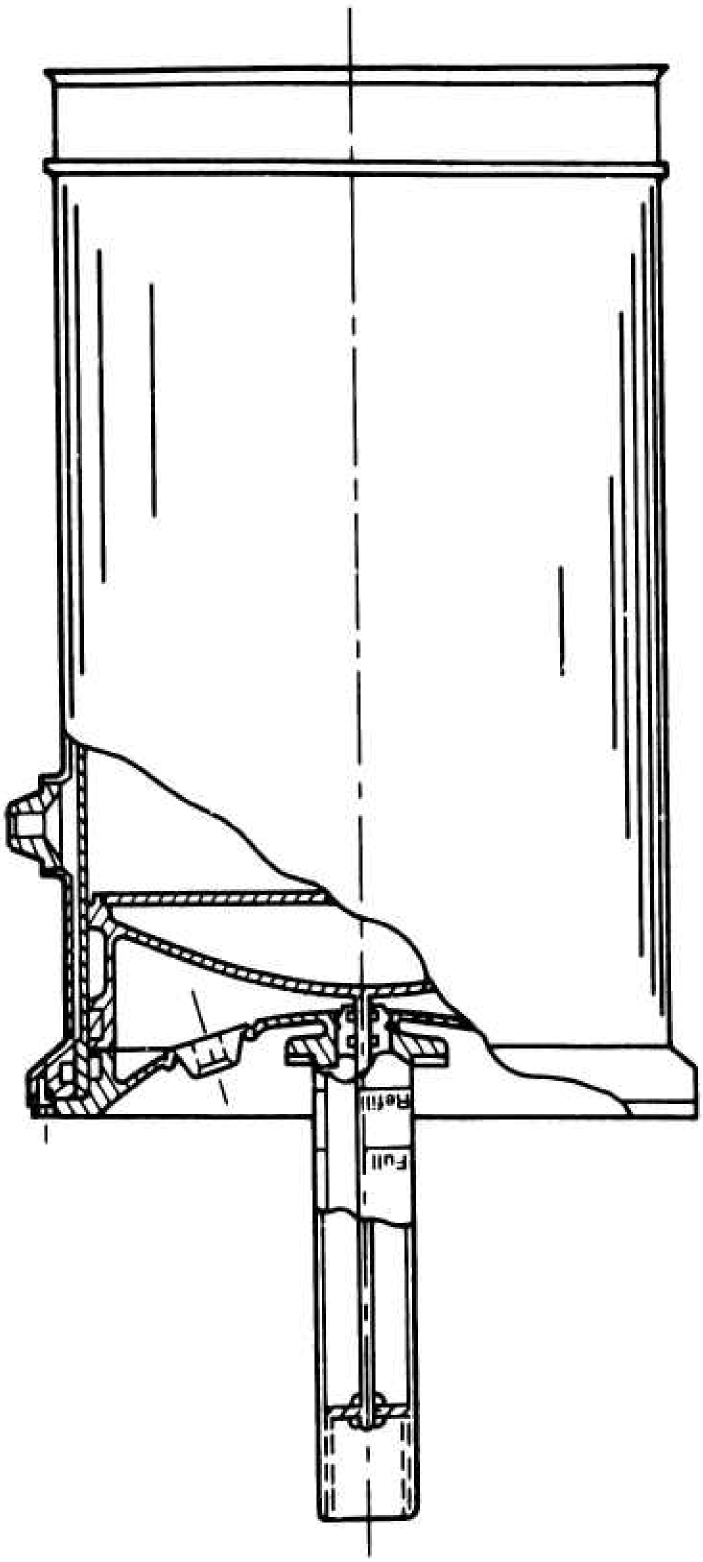


Figure 14. Pneumatic pressurized reservoir.

Regulated pressures of 40 to 100 psi are commonly used depending on the location of the reservoir in relation to the hydraulic pump inlet port and the dynamic effects required to satisfy the pump inlet conditions over its design operating range.

Bootstrap pressurization (Figure 15), depends upon system operating pressure working on a small diameter piston attached to the larger reservoir piston. The reservoir pressure is a function of the ratio of diameter between the small and large piston diameters. Some designs use an initial pressurization from a constant pressure gas source acting on the large piston to assure proper system starting characteristics. Once system pressure has built up, the bootstrap pressure is used to maintain reservoir pressurization. Table 5 shows reservoir specifics used in Grumman aircraft.

Since most Type II systems rely on separation between the energized source and the generating source to eliminate air contact, the position of the piston is an indication of the fluid level. However, the fluid level can be affected by such variables as compressed entrapped air on the fluid side of the piston, system temperature, and mode or condition of system components such as wings folded or spread swept back, etc. As an example, listed below are additional variables which affect the relative piston position.

- Initial fill condition
- System volume
- Fluid temperature
- Reservoir pressurization
- Entrained air in system
- Dissolved air in system.

Figure 16 shows theoretical fluid thermal expansion at varying system volumes. It becomes evident that visual indication can be in error if compensation is not given to fluid temperature. All fluid expansion and contraction usually occurs in the hydraulic reservoir.

Table 6 is a listing of various methods for sensing reservoir levels. A brief description as well as comments concerning each type is also given. Sketches showing the installation for each method of sensing are shown in Figures 17 through 25.

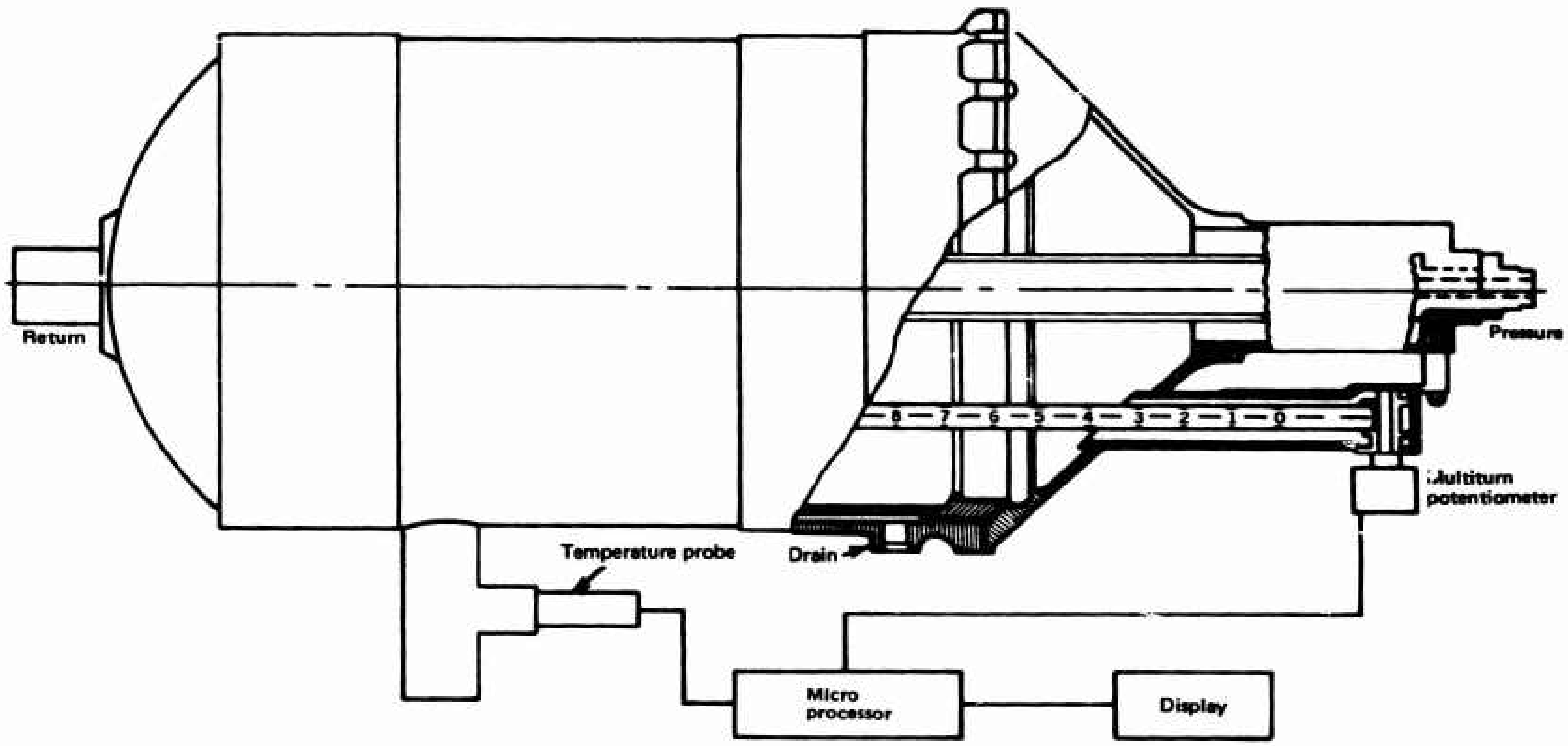


Figure 15. Bootstrap pressurized reservoir.

TABLE 5. HYDRAULIC RESERVOIR TABULATION

Description	Vehicle	A-6		EA-6B		E-2C		F-14	
	System	Combined	Flight	Combined	Flight	Combined	Flight	Combined	Flight
Total system fluid capacity		13.0 * (3000)**	5.6 (1290)	13.0 (3000)	5.6 (1290)	14.0 (3234)	5.83 (1347)	21.6 (4990)	12.0 (2772)
Total Reservoir Swept Volume		3.34 (772)	0.74 (171)	4.5 (1040)	1.1 (255.4)	3.34 (772)	1.3 (300)	6.4 (1478)	3.1 (716)
Full indication swept volume		4.5 (1040)	1.1 (253)	--- ---	--- ---	4.5 (1040)	1.83 (4225)	1.94 (448)	1.19 (275)
Refill to full volume		0.34 (78.5)	0.13 (29)	0.34 (78.5)	0.13 (29)	0.338 (78.1)	0.19 (44.2)	0.34 (78.5)	0.216 (49.9)
Piston									
Max stroke (full-empty)		13.31	7.75	13.32	7.75	13.32	9.37	19.0	14.5
Stroke between (refill-full)		1.0	0.875	1.0	0.875	1.0	1.0		
Pressurization		40***	40	45	45	40	40	105	105
Type		P	P	B	B	P	P	B	B

Code
- P = Pneumatic
- B = Bootstrap
- * = Gallons
- ** = Cubic inches
- *** = Pounds/square/inch

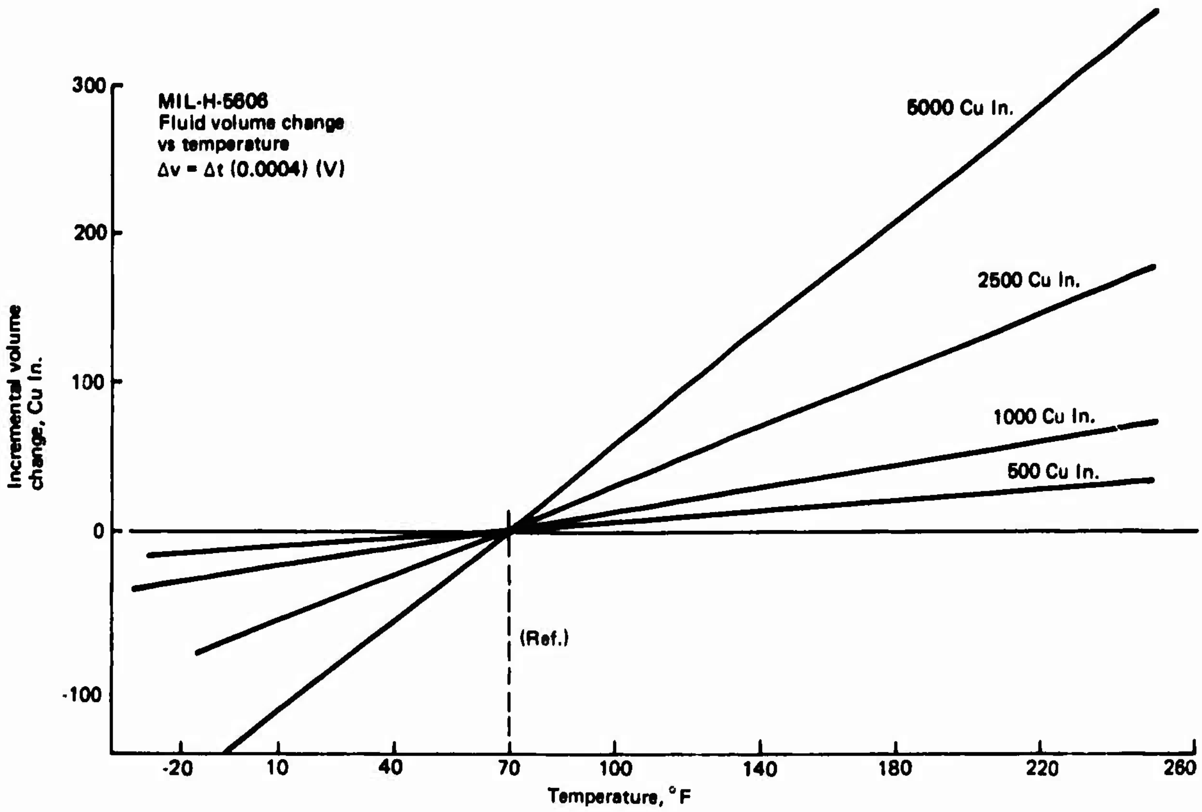


Figure 16. MIL-H-5606 volume change vs temperature.

TABLE 6. RESERVOIR LEVEL SENSING OPTIONS

Method	Type	Description	Comments
1	10 Turn rotary resistance	Typical rotary pot where resistance is proportional to angular rotation. . . .	Adaptable to F-14 bootstrap reservoirs with tape readout
2	Linear resistance potentiometer	Resistance wire moves along with piston. Fixed wiper picks up resistance change.	To have complete circuit two parallel wires must be used connected at piston base
3	Limit switches	Typical STDT miniature switches set at appropriate limits. LED at readout would be energized by switch tripper.	Similar to E-2C reservoir switches. Does not provide incremental or gradient readout.
4	Limit switches	Reed type switches which use moveable magnet to close contact & energize circuit	Not sensitive to initial set points as are microswitches. Can be encapsulated.
5	Hall effect sensors	Similar to reed type limit switches in that magnets are used	Not adaptable to large displacements.
6	Fiber optic readout	Uses LED for light source	Adaptable to both
7	Fiber optic readout	Uses highly reflective phosphorescent surface to show full or refill	Uses non-coherent light guide
8	Fiber optic readout	Perforated tape indicates refill condition	Extra LED plus additional perforation can indicate "full" condition
9	Fiber optic readout	Transparent tape with printed characters	Requires coherent type light guide to transmit numerals

Methods 1 and 2 (Figures 17 and 18) normally produce an electrical signal proportional to piston displacement. As shown in Figure 15, this signal, along with that from the temperature probe, will be fed to a microprocessor which in turn will indicate by means of an LED on the display panel whether the reservoir requires servicing.

Methods 3, 4, and 5 (Figures 19, 20, and 21) employ limit switches actuated by a tape or rod to indicate the fluid quantity in a reservoir (Ref. 8). To compensate for volume changes due to temperature changes, the limit switches will be mounted on slides that will be positioned by bimetallic type actuators.

Methods 6, 7 and 8 (Figures 22, 23 and 24) use fiber optics to transmit piston displacement at the display board. By using light reflected from a painted piston or indicating rod, a fiber optics light guide can indicate at the display board the position of the piston as a function of color.

Method 9 (Figure 25) would require a coherent or image-producing light guide in order to provide a readout of the printed characters on the tape. This type of light guide is larger in crossection and more expensive than a non-coherent type.

In pneumatic pressurization, the reservoir pressure decays relatively slowly due to the trapped volume of low pressure air. This is an advantage in that there generally will be some inlet pressure available to the pump or pumps during start up. However, this also makes it difficult to establish the amount of entrained air in the oil because the system is under pressure when reading piston position. In a bootstrap pressurized reservoir, the initial piston position is read while the system is unpressurized. When the system is pressurized, the piston will move as a function of system compliance, entrained air, and accumulator fill. Since piston travel due to system compliance and accumulator fill can be established for a particular aircraft, then any additional travel would be indicative of the quantity of entrained air. The logic in Figure 26 is applicable to the F-14 aircraft wherein it has been established that a piston travel greater than one inch is the result of entrained air.

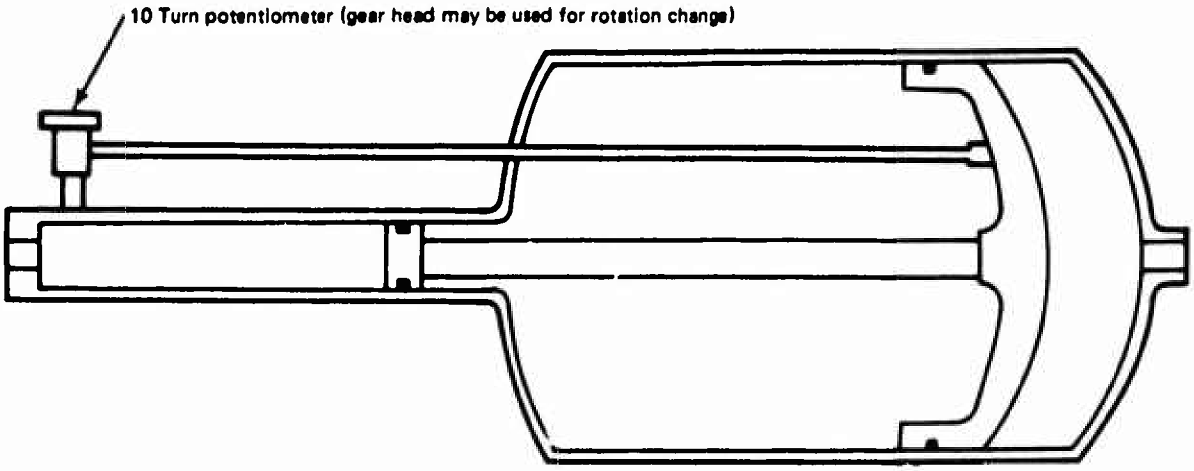


Figure 17. Rotary potentiometer reservoir level sensor: method 1.

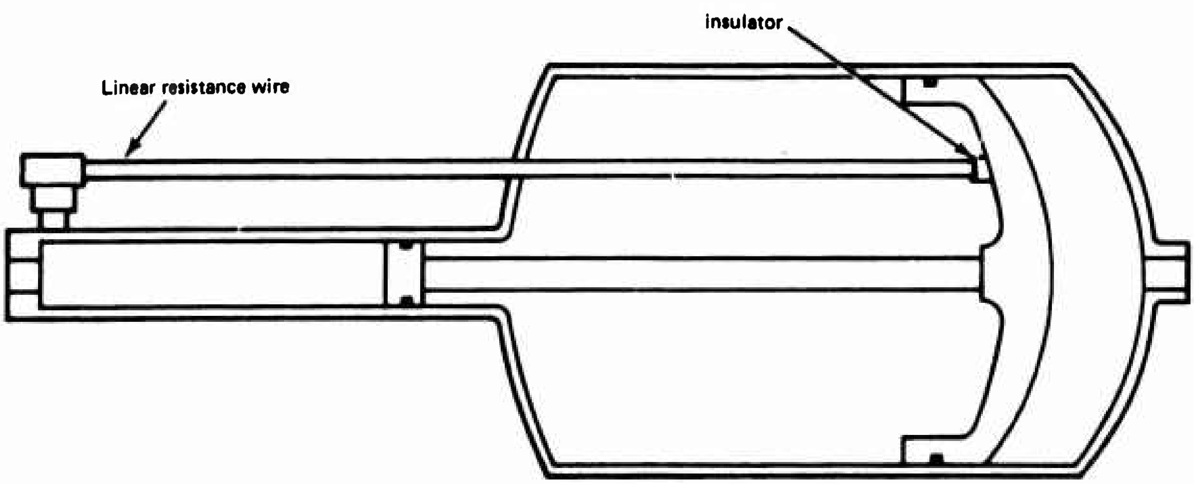


Figure 18. Linear potentiometer reservoir level sensor: method 2.

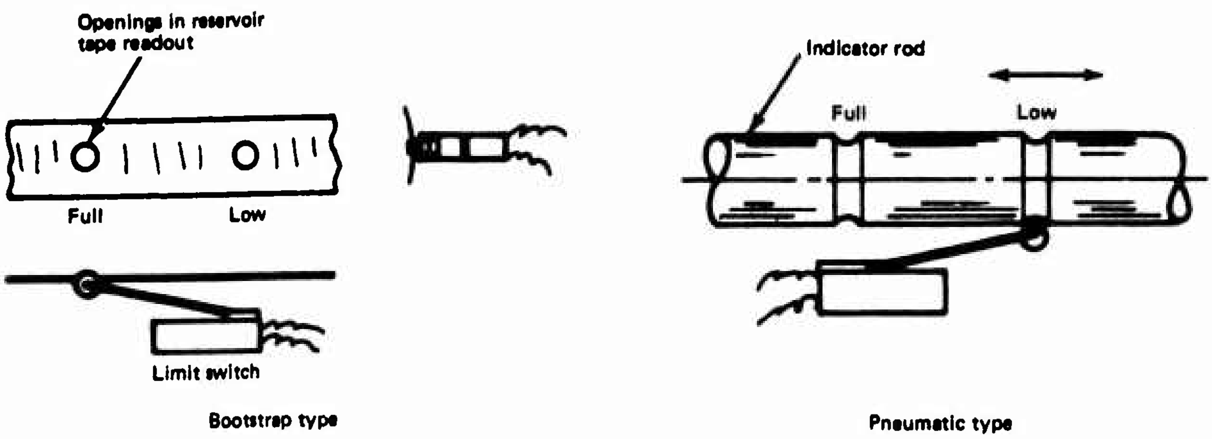


Figure 19. Limit switch type indicators: method 3.

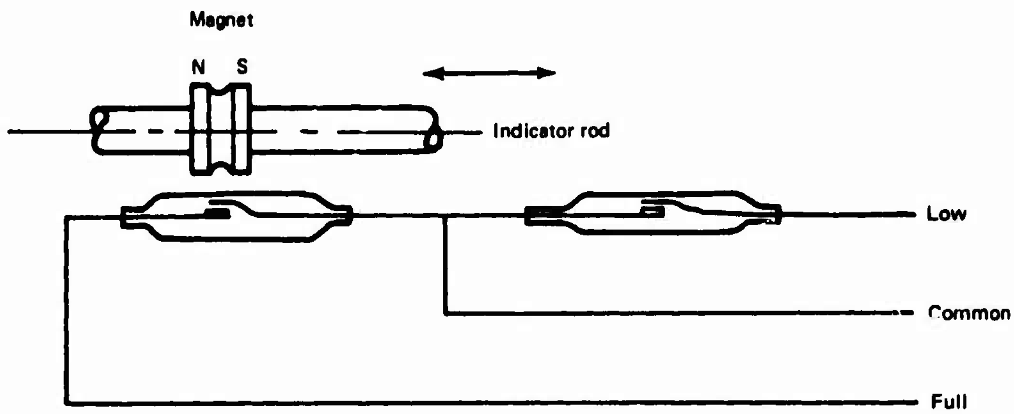


Figure 20. Reed type limit switches: method 4.

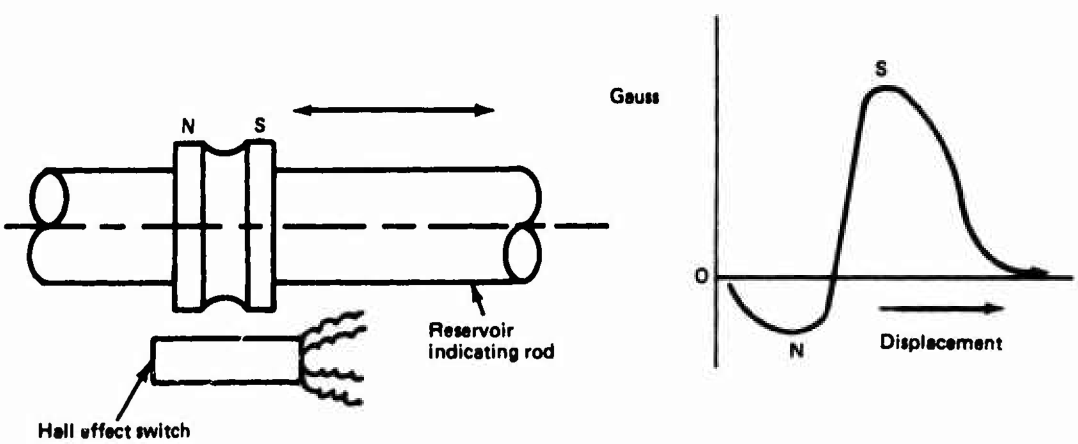
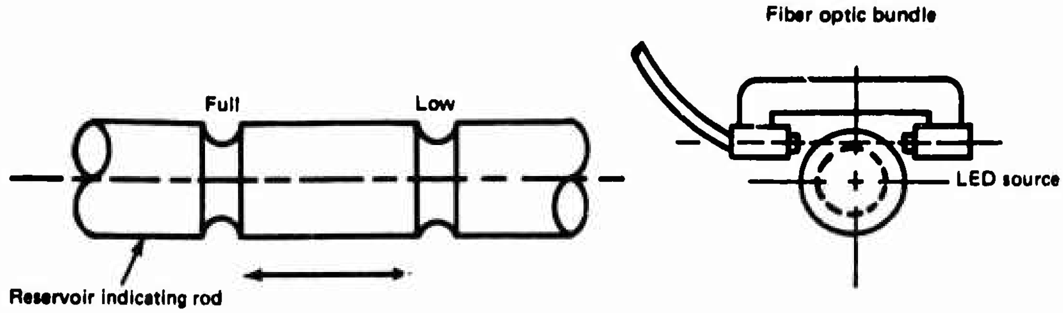


Figure 21. Hall effect sensor: method 5.



Notch allows LED light source to transmit color back to readout panel.

Figure 22. Fiber optics sensor: method 6.

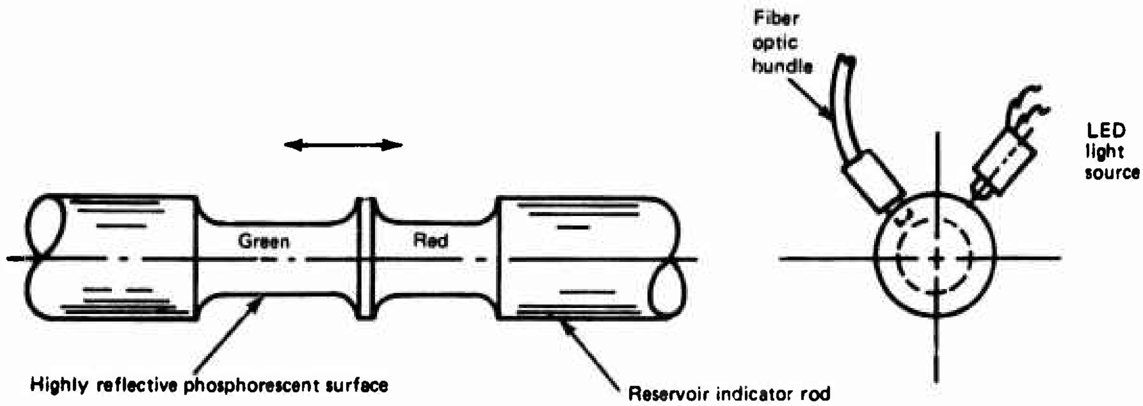


Figure 23. Fiber optics sensor: method 7.

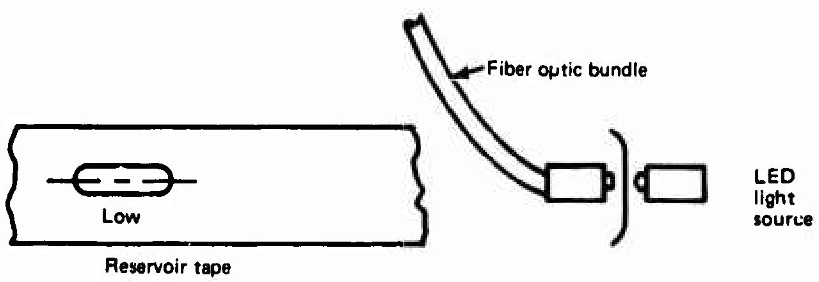


Figure 24. Fiber optics sensor: method 8.

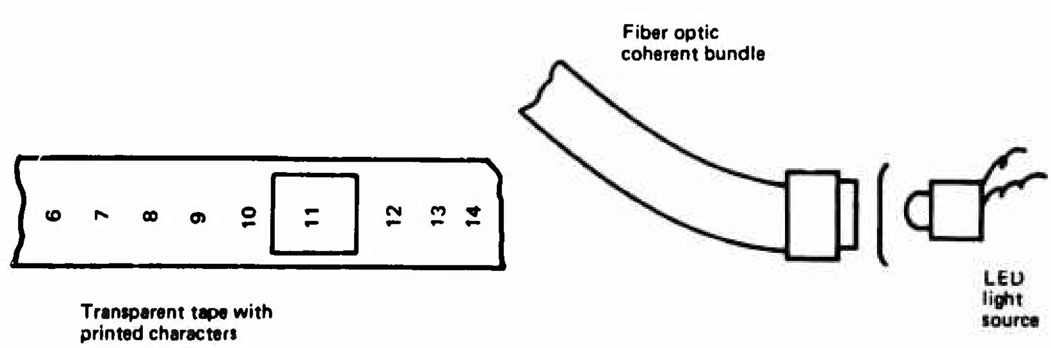


Figure 25. Fiber optics sensor: method 9.

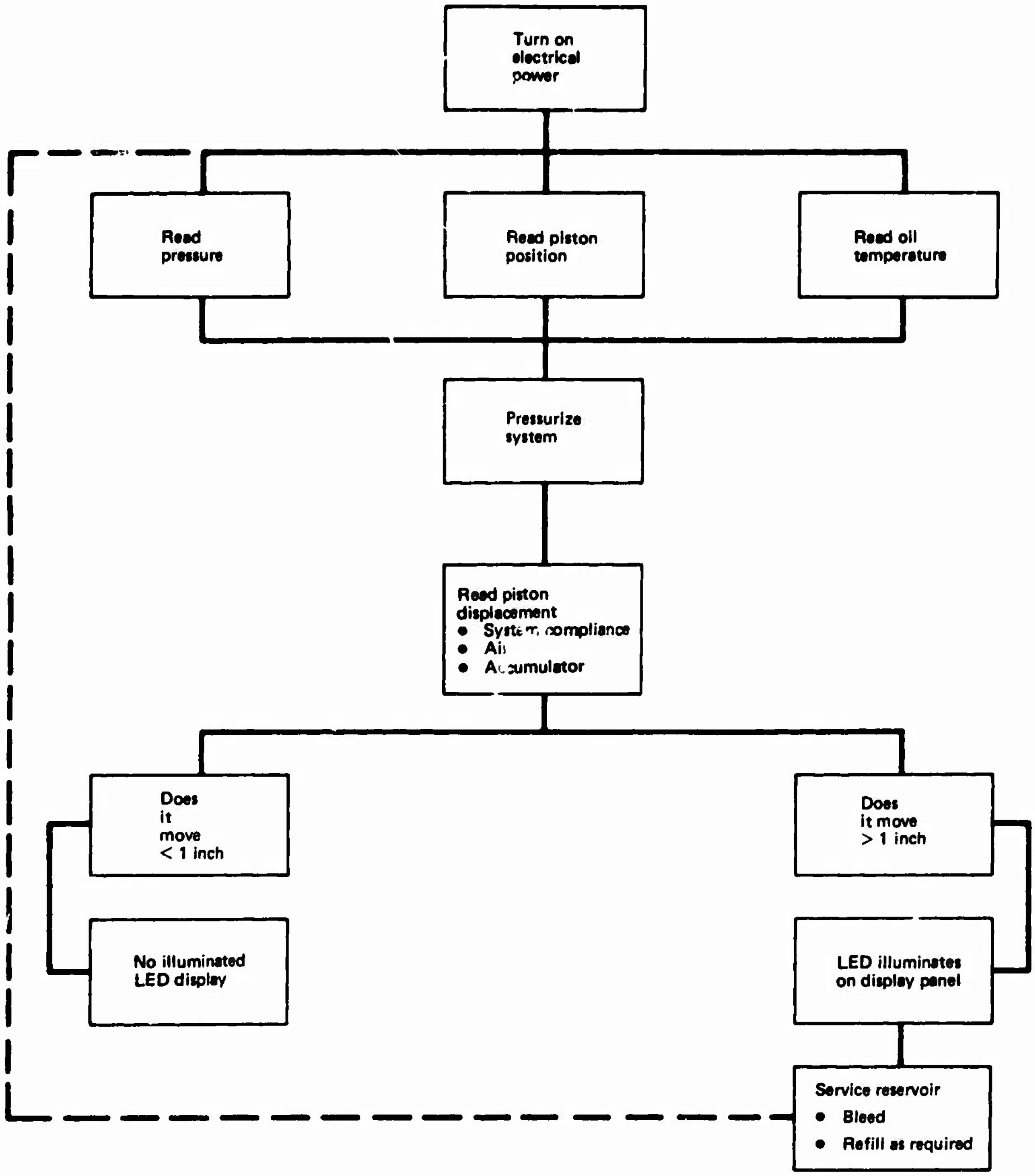


Figure 26. Typical reservoir level sensing logic.

A reservoir level sensing system could employ a simple logic circuit utilizing a microprocessor to determine if the level is in or out of limits. The microprocessor can handle simultaneous multiple inputs and compare the results against a pre-programmed envelope restraints. Variables like fluid temperature compensation, entrained air, system compliance, and accumulator charge could easily be handled on an 8 or 16 input unit. Analog inputs to the microprocessor could vary from 0 to 10 VDC. A typical reservoir sensing logic is shown in Figure 26.

2.3.4 Accumulators

Accumulators are frequently used in operational aircraft hydraulic systems. They dampen out pump ripple or supply hydraulic power for momentary over-demand conditions. Another frequent use is as prime source for subsystem or component actuation such as ram air turbine extension systems or brake systems. See Table 7 for typical Grumman aircraft uses.

TABLE 7. HYDRAULIC ACCUMULATORS (COMPILATION)

Vehicle	System	Location System	Size In.^{3}	Precharge, psi	Part no.
A-6E	Combined	Brake	50	800	128SCH137-3
		Main	25	2000	128SCH137-1
		RAT	50	500	128SCH137-3
	Flight	Main	25	2000	128SCH137-1
EA-6B	Combined	Brake	65	800	128SCH137-7
		Main	25	2000	128SCH137-1
		RAT	25	500	128SCH137-1
	Flight	Main	25	2000	128SCH137-1
E-2C	Combined	Main	100	2000	128SCH137-5
		Brake	50	800	128SCH137-3
	Flight	Main	50	2000	128SCH137-3
F-14	Combined	Main	50	1800	A51H9043-1
		Brake	50	950	
		Brake	50	950	
	Flight	Main	75	1800	A51H9219-1

In order to be useful and functional most accumulators must be precharged with an inert compressible gas. The precharge pressure is determined by the intended use and system demand requirements. Precharge pressures can vary from 500 psi to 2000 psi. Under stabilized conditions, the precharge pressure follows the ideal gas laws for constant volume.

$$\frac{P_1}{P_2} = \frac{T_1}{T_2} \qquad (V = K)$$

where: P_1 = initial absolute pressure at temperature T_1

P_2 = final absolute pressure at temperature T_2

T_1 = initial charge reference temperature (^{o}R)

T_2 = temperature other than reference

In order to determine if an accumulator is at the proper precharge pressure, two conditions must be met:

- System pressure must be depleted or accumulator discharged manually (in closed subsystem)
- Fluid (gas) temperature must be known.

To utilize this approach in the HYCOS system, consideration must be given to both variables. If a thermal compensated pressure switch is utilized which has the same operating slope as the ideal gas, then a low charge can be detected at any system (fluid) temperature within limits. Temperature compensation can be built within the switch depending on the use. See Figure 27 for one switch concept.

Another possible alternative is to utilize a low pressure switch setting which is below that normally encountered during normal service, i.e., if we refer to Figure 28 the switch setting could be set at approximately 1500 psi (as shown at $56^{o}F$) and this would remain constant as the temperature increased to $275^{o}F$. This is based on the assumption that 1500 psi minimum precharge pressure would be adequate to perform the intended design function.

In cases where the accumulator is used for stored energy sources such as ram air turbine or APU starting, piston position must be known if one is to determine proper precharge pressure. Figure 29 shows piston displacement versus various precharge pressures for a 50 cu in. accumulator.

Methods of detecting piston position within a cylinder is difficult without the use of oscillating or shaft seals. Areas which require further investigation are:

- Reflected light
- Internal displacement sensor
- Magnetic coupling.

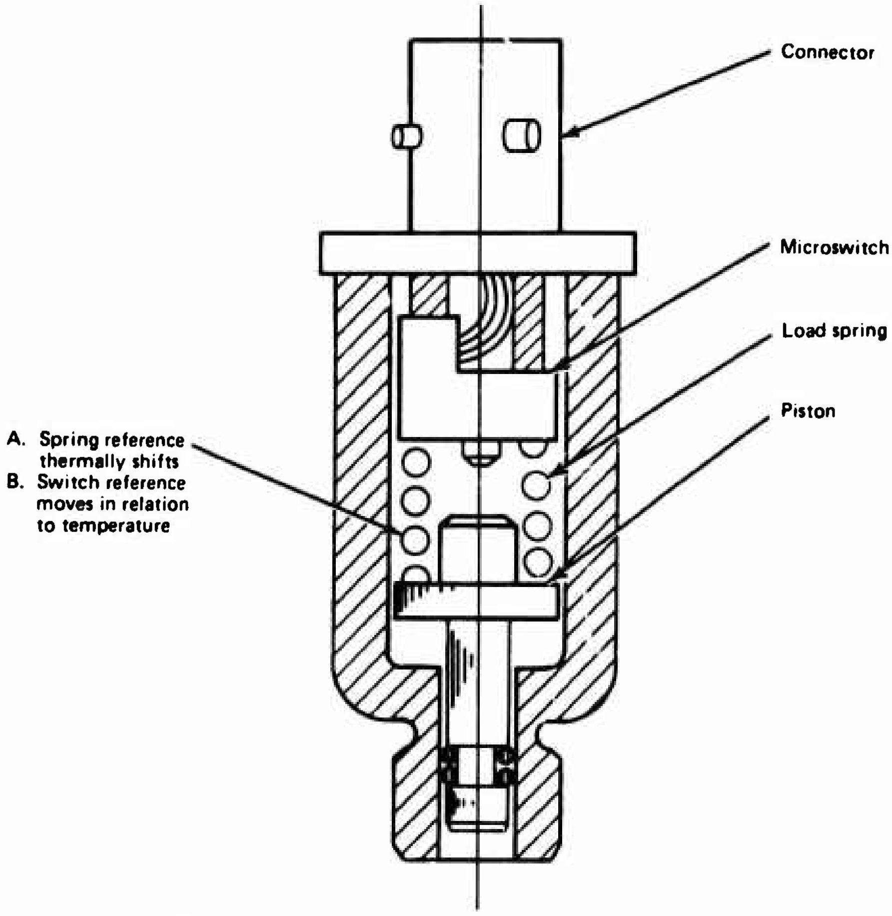


Figure 27. Temperature compensated switch.

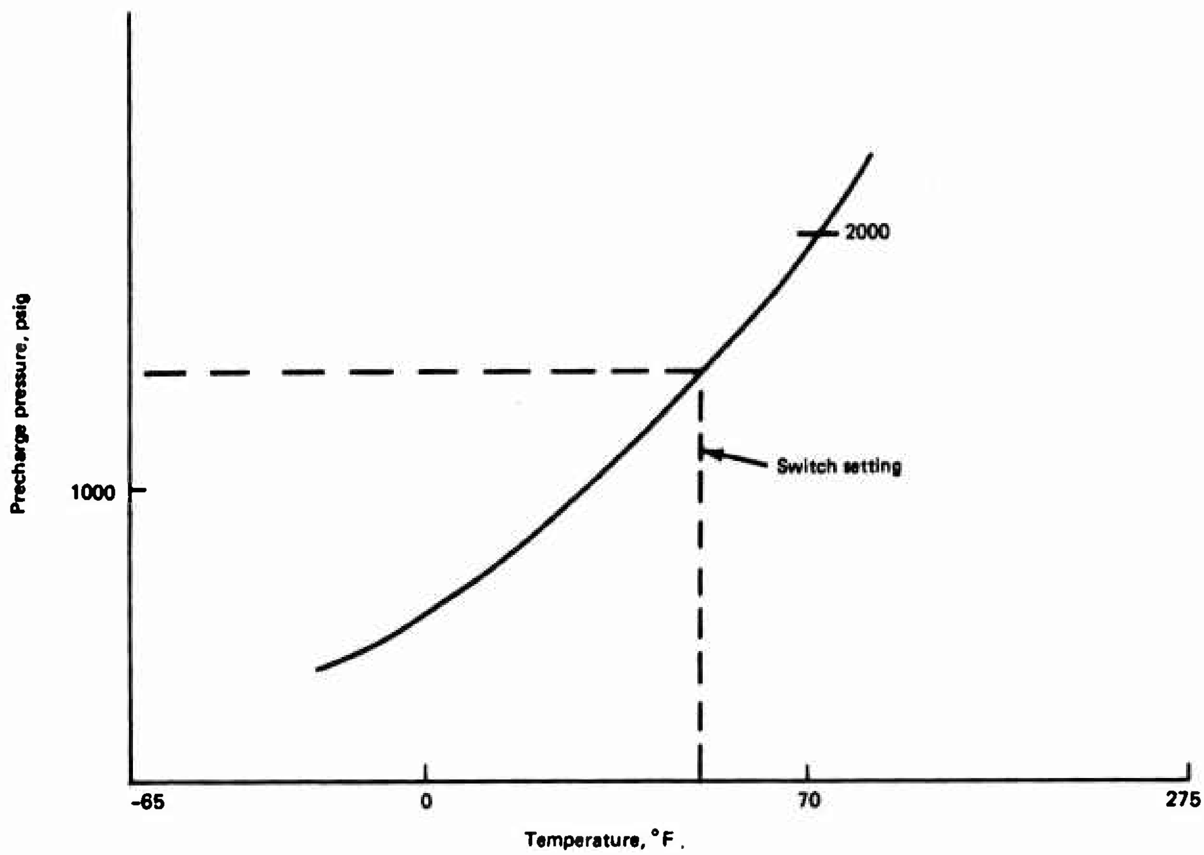


Figure 28. Precharge variation as a function of temperature.

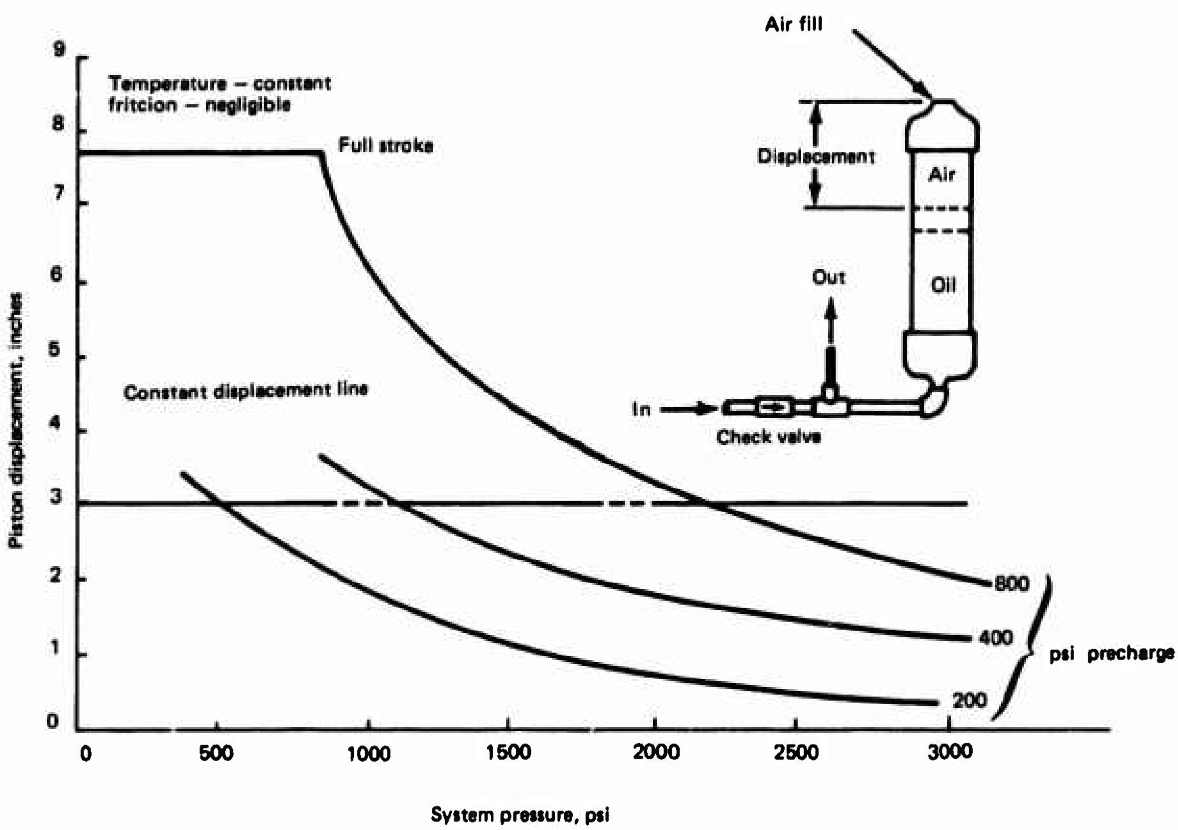


Figure 29. Piston displacement for a 50 in.^{3} accumulator vs system pressure.

If a pressure transducer signal is coupled to a piston displacement sensor and the inputs channeled to a microprocessor, then it is possible to determine at any point whether an accumulator has the proper precharge pressure since the PV relationship for gas holds.

In cases where the accumulator piston traverses to a discharge position, a simple pressure switch is adequate to detect a low precharge condition.

2.3.5 Gear Shock Struts

Factors which affect proper servicing are threefold:

- Air pressure
- Fluid level
- Aircraft load.

Current maintenance operations call for the depletion of strut pneumatic pressure, removal of the fluid level plug, and adding fluid until a full condition exists. The plug is then reinstalled and the strut is pressurized until the proper pressure is determined for the required piston displacement. Figure 30 shows a typical main gear shock strut curve. Figure 31 shows how this curve would vary if the strut is over or under pressurized. Remote sensing can be accomplished by one of several means. Strut pressure can be measured by means of a pressure transducer.

2.3.5.1 Strut Displacement

Strut displacement can be measured one of three ways:

- Linear Reflected Light-When a light source is generated from the stationary part of the strut and reflected from the movable part of the strut, the position of the light beam is an indication of strut displacement. Output could be ohms or volts (Figure 32). This type is sensitive to available light intensity and possible wheel debris.
- Linear Actuated - Rotary Potentiometer - A wire driven spring return rotary pot is activated by strut position - as the strut extends the pot resistance changes, which is correlated to displacement. See Figure 33.
- A rotary pot could be affixed to one drag link of the main or nose gear and drag link rotation can be correlated to strut extension. Maximum angular rotation would be less than 180^{o}. See Figure 34.

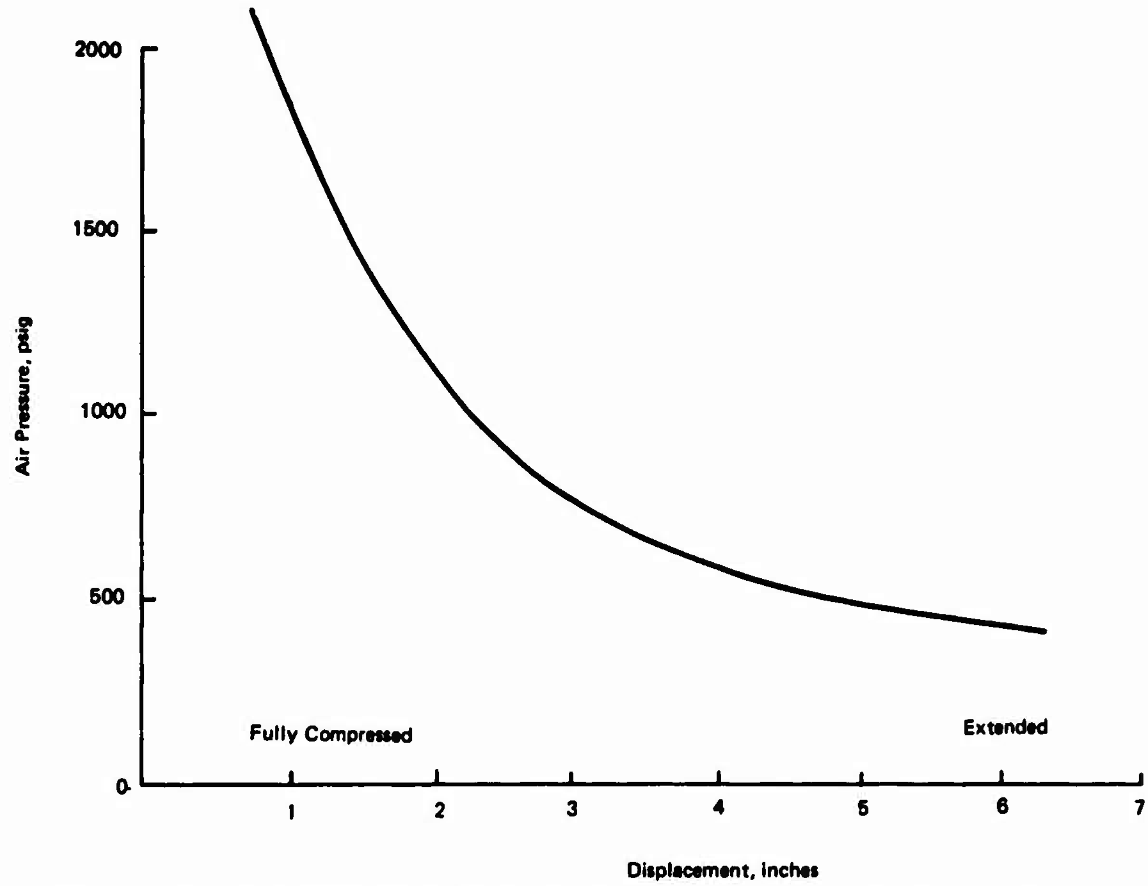


Figure 30. A-6 Main gear shock strut pressure vs strut displacement.

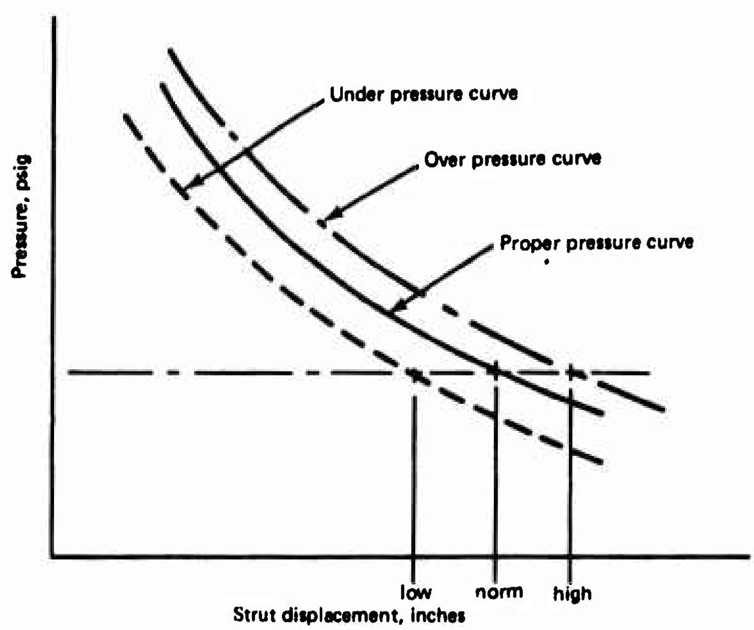


Figure 31. Pressure vs displacement variation.

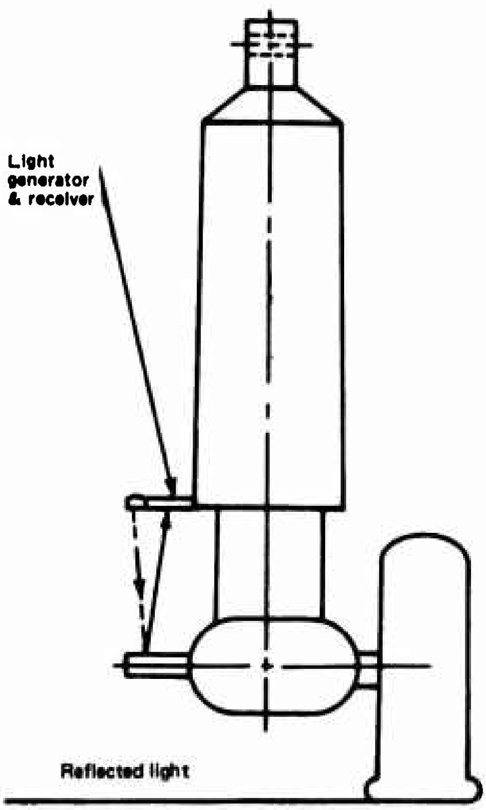


Figure 32. Reflected light strut displacement concept.

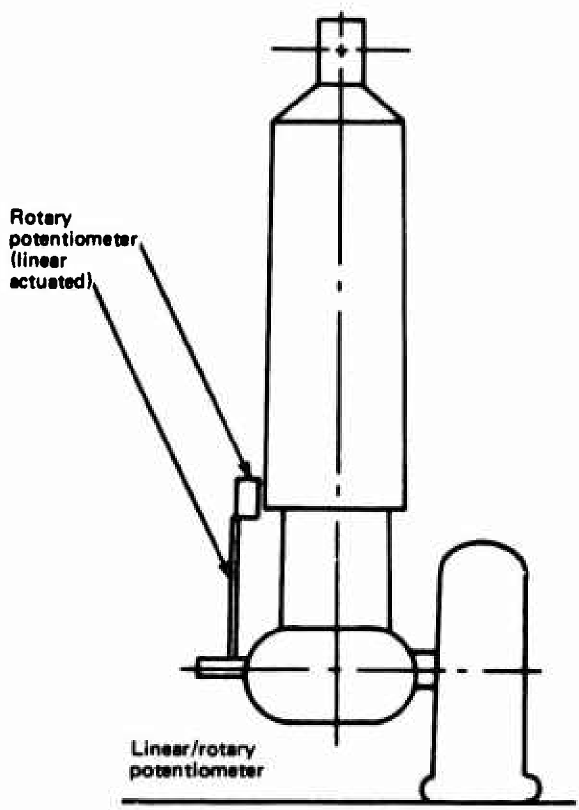


Figure 33. Rotary potentiometer displacement concept.

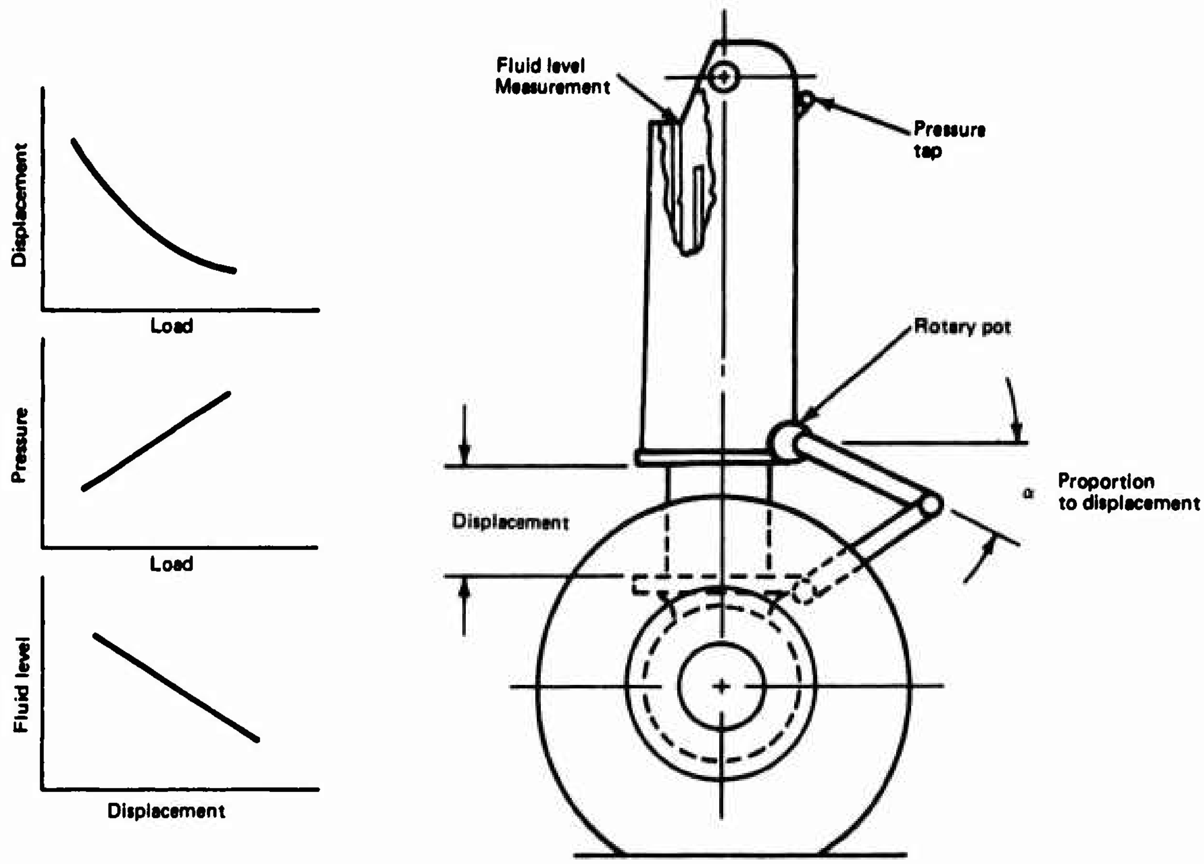


Figure 34. Shock strut pressure/level concept.

2.3.5.2 Strut Displacement Curve

If strut is properly pressurized, the displacement will follow the properly pressurized curve. The variables, displacement and pressure, could then produce a combined signal which would be read out at the readout panel. Signal processing would be required to establish an in or out-of-tolerance condition.

2.3.5.3 Strut Liquid Level Measurements

Measuring liquid level within a steel pressurized strut whereby the liquid may be (all liquid, foamy, all gas-no liquid) could prove to be a difficult task.

Methods which may be considered for further investigation and development are:

- Fiber optics
- Capacitance type probes
- Mass measurement
- Pressure rise
- Magnetic coupling
- Ultrasonics.

2.3.5.4 Fiber Optics

Fiber optic probes have already been developed for liquid level measurement in fuel systems (Grumman proprietary). The principle of operation is that the refractive index of the fluid is the same as the fiber so that when the fluid level reaches a predetermined point - light can be transmitted to the readout panel or an optoelectrical relay which precludes an LED from illuminating until the optic circuit is complete. When the optical circuit is incomplete the relay closes, illuminating the LED indicating low fluid level.

The refractive index of foam and its effect on readout is not presently known and is the subject of further development effort.

Some limitations of this concept are the available reservoir void volume for inclusion on the fiber optic probe, its method of installation and retention.

One method that is possible is shown in Figure 34. This shows the fiber optic probe inserted through the fill and pressurize port and retained by means of an adapter. The adapter also provides a fiber optic coupling and a boss for a pressure transducer/ switch and a fill valve.

2.3.5.5 Capacitance Type Probe

It has been shown that a capacitor type probe can and does function in a vapor liquid phase (see section on Fluid Conditioning). A capacitance probe placed in the strut could also measure liquid level and take into account vapor phase or foaming which occurs in the strut when it is functioning.

If the probe comprises the ID of the strut wall it can be read for level, taking into account a foam level as well. The probe itself must be insulated from the strut body for effective operation. Temperature compensation must be provided to take into account the temperature extremes the strut may be subjected to during cold soak at altitude and hot soak at desert type temperatures.

2.3.5.6 Mass Measurement and Pressure Rise

Two other possible methods of measuring liquid level in struts. Because of their associated complexity, their approach is not justified.

2.3.5.7 Magnetic Coupling

Magnetic coupling can only be effective or applied where the pressure vessel is of a non-magnetic material and the fluid level has floating sensor. At the higher strut pressures this method might pose a problem.

2.3.5.8 Ultrasonics

Ultrasoncis have been employed to measure fluid level in large tanks with no other mechanical interface. In the case of struts, because of their multitudenous complexity, this method does now show significant promises.

2.3.6 Pneumatic Bottles

Pneumatic bottles are used primarily as emergency power energy sources on aircraft hydraulic systems, this includes:

- Landing gear door actuation
- Landing gear cylinder actuation
- Door and gear lock actuation.

Emergency power sources are called upon to function when a hydraulic system has failed. It then relies on compressed stored gas to provide the energy to perform specific functions normally handled by the hydraulic system.

There are other uses of compressed gases such as:

- Reservoir pressurization
- Canopy actuation.

Table 8 shows some of the uses pneumatic bottles are put to on a variety of hydraulic systems. Shown also is charge pressure and pneumatic bottle volume.

Bottle pressure varies as a function of gas temperature. If a bottle is charged to a specific value at $70^{o}F$, the bottle pressure will rise as the bottle and gas temperature increases. It will also fall when the temperature decreases. An assumption of equilibrium conditions is made.

To detect this variation in temperature and compensate for pressure changes, a temperature compensated pressure switch is required. If we assume that 300 psi below the normal charge pressure is the minimum required, then it would be desirable to have a switch compensate for thermal variations. Figure 35 shows such a plot of a temperature compensated pressure switch.

TABLE 8. PNEUMATIC BOTTLES

Aircraft	Function	Spec no.	Volume, cu in.	Pressure, psi
F-14	Canopy Canopy Landing gear	A51H9016-3 A51H9103-1 A51H9077	225 14.7 400	3000 3000 3000
A-6	Canopy Aft door Uplock cyl Fwd door cyl Fwd door cyl	98SP2266-1 98SP1997-3 128SCH161-3 128SCH161-1 128SCH161-1	14.6 50 50 30 30	2450 at 70° F
E-2C	Landing gear	123SCH 146-1	300	2400 at 70° F
EA-6B	Aft door M.G. uplock M.G.R. fwd door M.G.L. fwd door Canopy Canopy Canopy Canopy	98SP1997-3 128SCH161-7 128SCH161-1 128SCG161-1 1128SCH400-1 1128SCH401-1 1128SCG401-3 98SP 1997-7	150 50 30 30 1300 150 200 50	2450 at 70° F

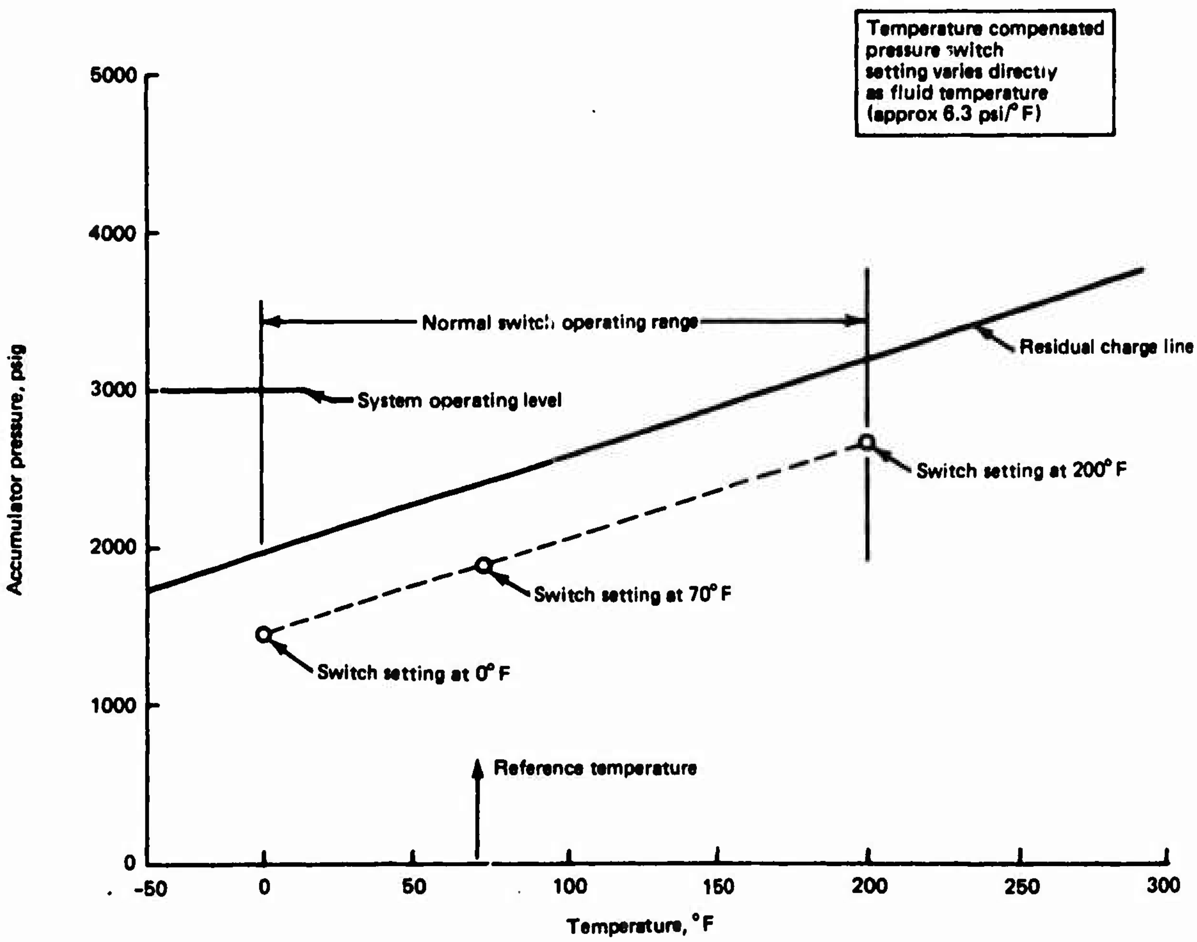


Figure 35. Pressure vs temperature variation.

One theoretical approach might be to use a bimetallic unit which shifts the reference point as the temperature changes (Figure 36). Another more practical approach might be to use an inert gas to sense temperature as is done by the Neo-Dyne temperature compensated pressure switch shown in Figure 37. The size of this unit is large in relation to the available installation envelope.

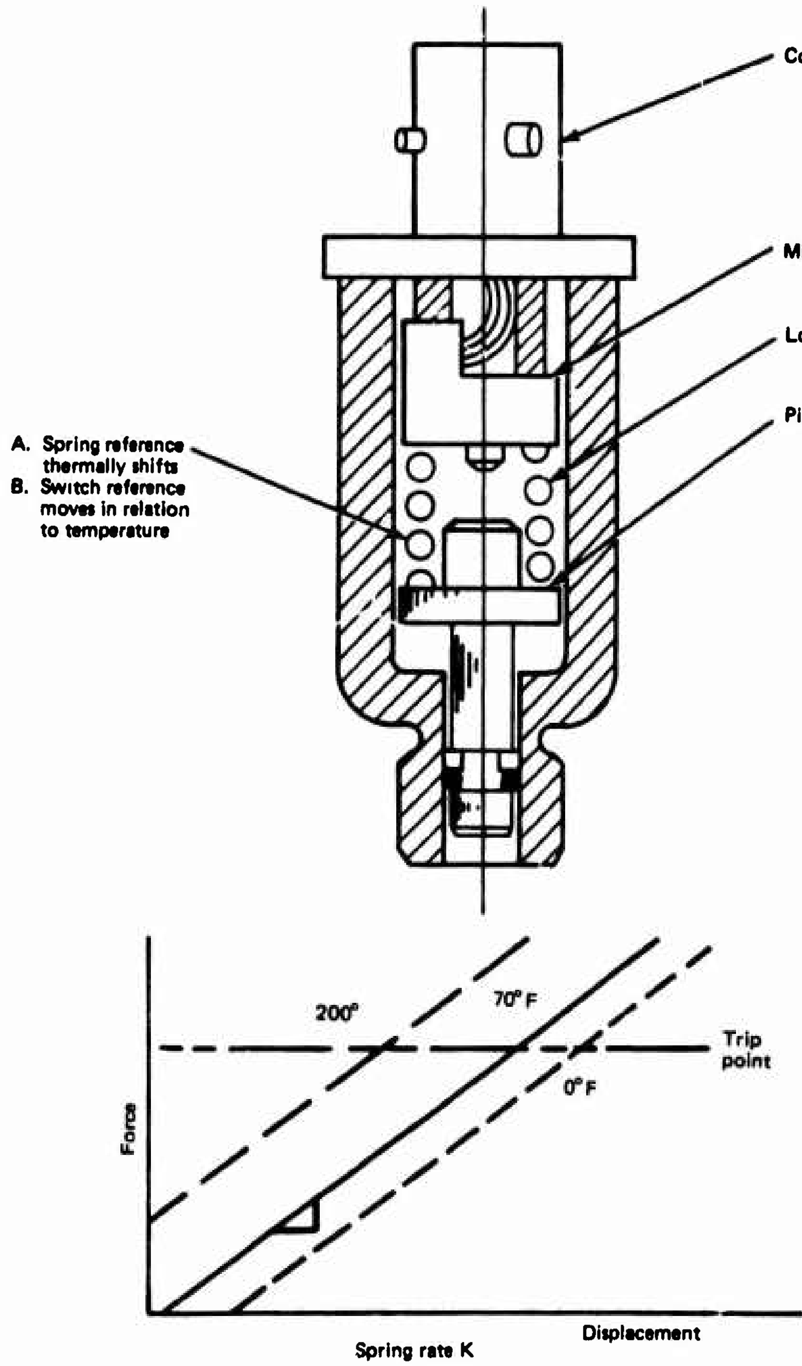
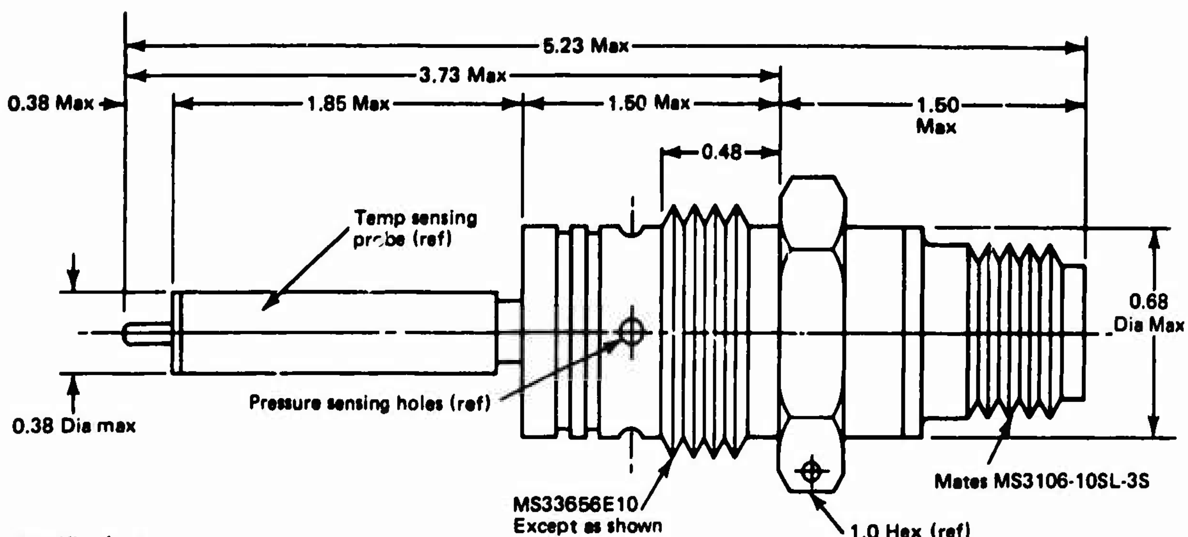


Figure 36. Temperature compensated pressure switch (concept).



Specifications

Ambient Temp	0° F	70° F	200° F
Decr press(nom)	1400 psig	1820 psig	2600 psig

Pressure rating:
Normal system: 3000 psig max

Media: Inert gases

Ambient and media temp:
Operating: 0 to 200° F
Non-Oper: -65 to 275° F

Figure 37. Temperature compensated pressure switch (NEO-DYNE).

2.3.7 Chemical Dryer

The condition of a chemical dryer can be determined by observing the color of an indicator located on the downstream side of the unit. As the desiccant begins to become ineffective, the increased humidity of the existing air will cause a color change in the indicator. This passive type system is highly reliable inasmuch as no switches or moving parts are required. The indicator can be incorporated in the downstream end of a newly designed housing. A small light source such as an LED will be used to illuminate the indicator. The reflected light will be picked up by a fiber optics cable or light guide and displayed at the checkout station. A small window in the housing will permit direct viewing of the indicator. The incorporation of this system will add very little to the weight of the housing. This arrangement will also allow the use of standard-size desiccant cartridges.

A small transparent cartridge is also available which can be installed in series on the downstream end of an existing cartridge (Figure 38). The low pressures required for hydraulic reservoirs make possible the use of a transparent plastic housing. An LED and a fiber optics cable can be readily attached to the housing.

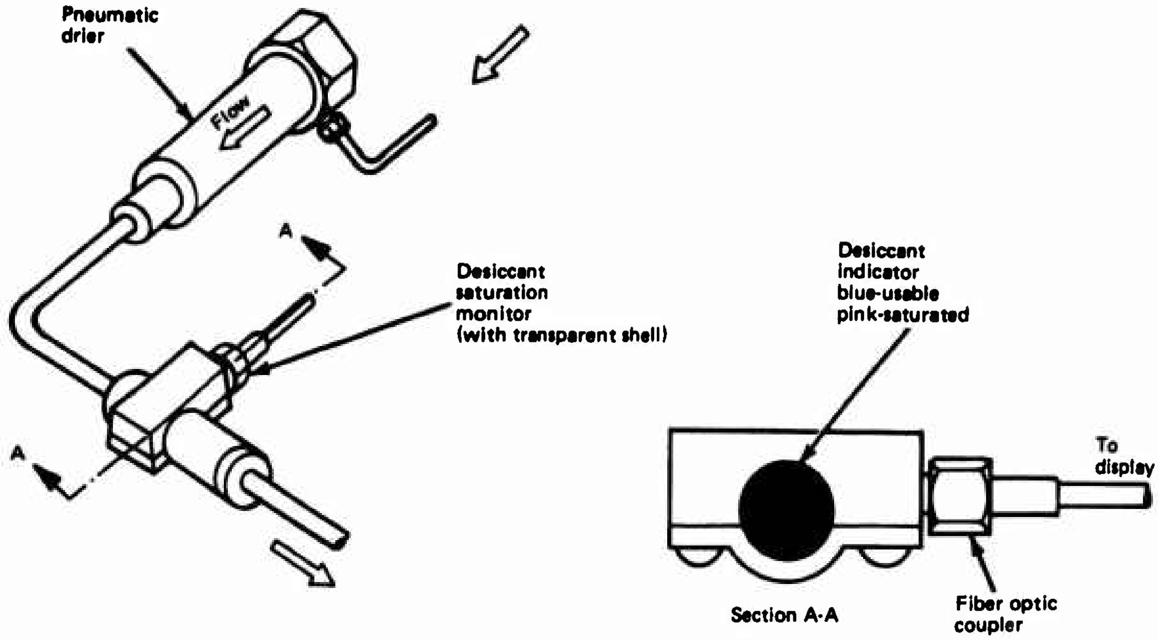


Figure 38. Desiccant saturation monitor.

2.4 SENSORS AND READOUT

2.4.1 Fluid Processing

2.4.1.1 Fluid Contamination Levels

Fluid contamination levels can be determined with an on-line particle counter connected to a sampling valve on the pressurized system. Sampling flow rate can be controlled by using an appropriate restrictor.

Two types of contamination monitors were considered during the HYCOS study phase effort. Both types provide an analog readout. One type is made by HIACC Division of Pacific Scientific Company, Claremont, California. This unit is shown and described in Figure 39. The other unit is manufactured by the Millipore Corporation of Bedford, Massachusetts and is shown in Figure 40. Where specific fluid contamination levels are required, digital/multi-channel equipment can be utilized.

Figure 39. HIAC Model PC-120 contamination monitor.

Figure 40. Millipore microspan unit under development for ground support applications

- Principle of operation – Relies on dielectric constant of fluid. Air, and particulate matter changes capacitance and is read on analog meter
- Equipment limitations:

Temperature–	160° F
Pressure–	80 psi
Lower limit–	15μ
Contamination level readout–	4 and above (Navy)

2.4.1.2 Vapor Liquid Phase Detection

As part of the HYCOS study effort, a model 600 Vapor Liquid Meter manufactured by IKOR Incorporated of Burlington, Massachusetts was evaluated in a small hydraulic circuit. The IKOR Vapor/Liquid meter consists of a capacitance type in-line sensor coupled to an analog meter display which is calibrated to the dielectric constants of the fluid. Typical delectric fluid constants are:

$$\left.\begin{array}{ll} \text{Air} & 1.00 \\ \text{JP-3} & 2.10 \\ \text{Benzene} & 2.28 \\ \text{MIL-H-5606} & 2.33 \end{array}\right\} \text{at } 25^{\circ}\text{C}$$

The sensor plates form a quadrafiler array within the ID of the sensor tube thereby minimizing pressure loss. Since fluids exhibit a dielectric constant of greater than 1, it becomes possible to determine the vapor/liquid phase of a moving fluid stream by measuring the change in capacitance. The V/L meter is initially calibrated for a dielectric constant of 1 for all gases or vapors. The other end of the scale is calibrated for the dielectric constant of the system fluid. In this case it is 2.33. Calibration points are then locked to prevent inadvertent shift. Fluid is then passed thru the sensor simulating flow conditions (Figure 41).

A small test setup utilizing a hydraulic reservoir, transfer pump, V/L meter sensor and a transparent viewing block in front of the sensor with appropriate interface fittings was configured.

Figure 42 shows photos of the test setup and readout. A single channel oscilloscope was attached to the meter to determine signal condition.

Flow was established thru the test circuit and entrapped air was bled from the reservoir. As witnessed by the transparent viewing block, the throttling valve was then throttled to simulate inlet restriction.

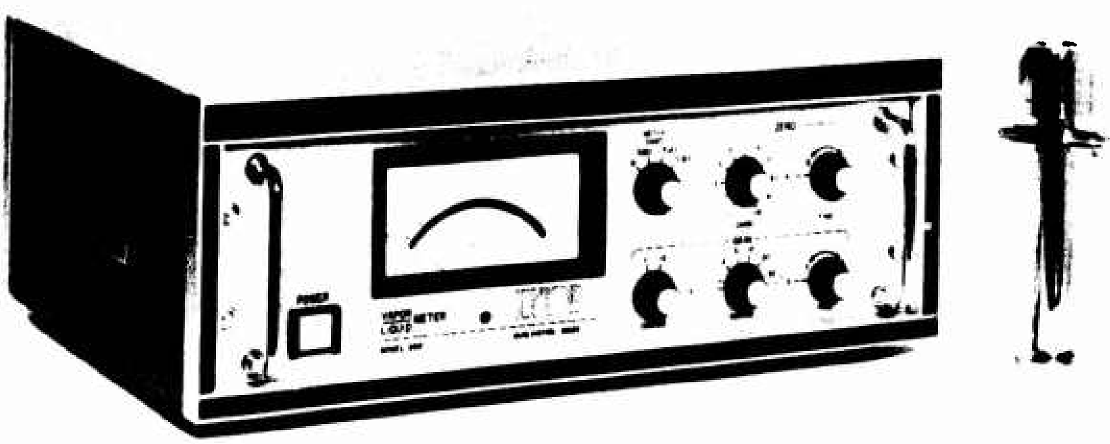


Figure 41. IKOR Model 600 vapor liquid meter.

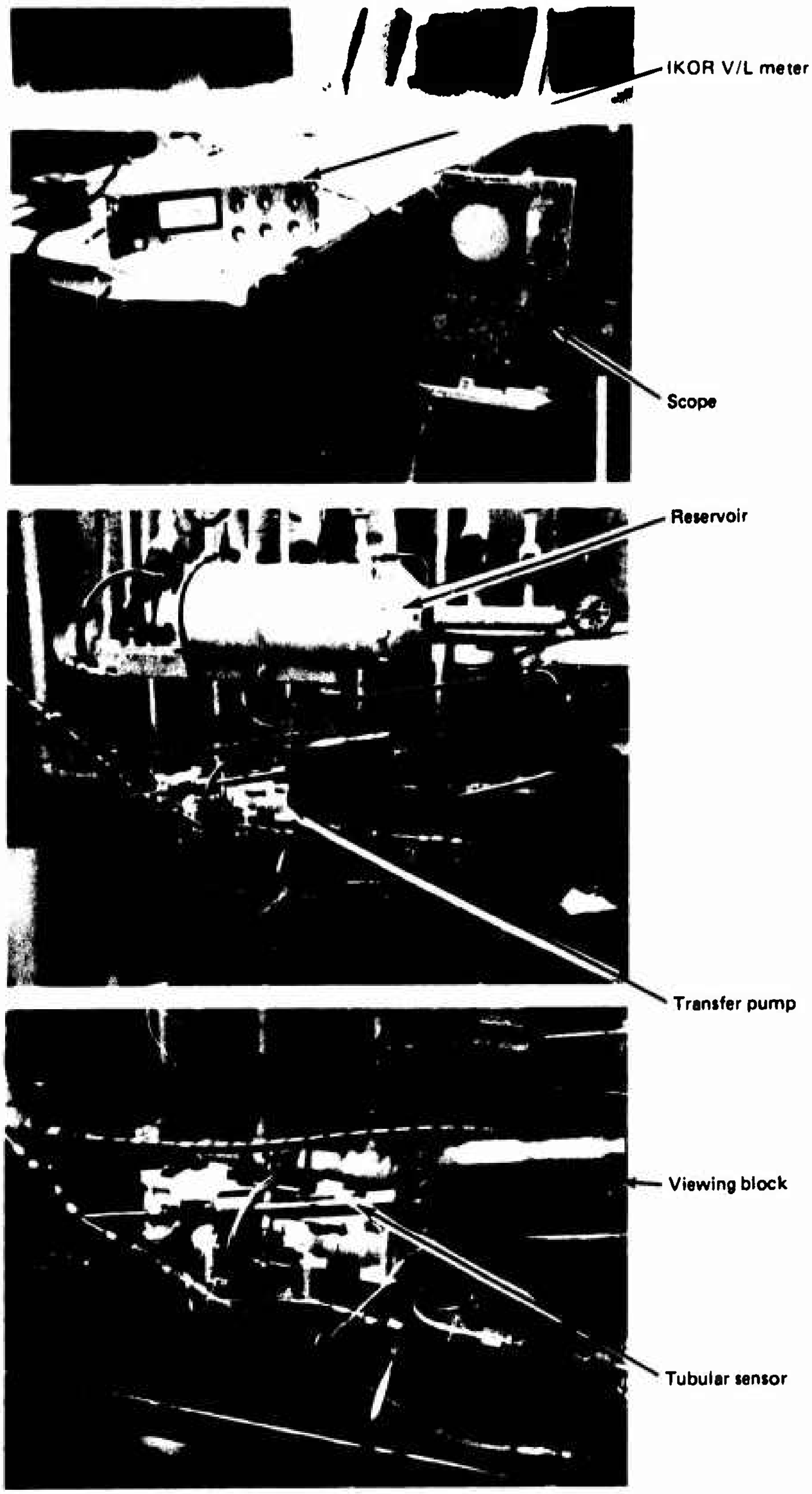


Figure 42. Vapor liquid meter lab demonstration.

Immediately, cavitation became evident in the sight block and the V/L meter read 25 - 30% vapor/liquid ratio. This test was repeated several times. The meter effectively indicated the presence of cavitation in a hydraulic pump inlet line.

The second phase of testing injected air into the hydraulic circuit. During operation (fluid circulating), the V/L meter indicated 30% air/oil ratio. This was verified by the viewing block. At the termination of this test when the air was bled from the system, a null shift in the reference point occurred. This is normal since the dielectric constant of a fluid changes slightly as the fluid temperature changes. Temperature compensation or conducting the test at a constant temperature would alleviate this condition.

Next, a slug of AC fine test dust in a MIL-H-5606 slurry was passed thru the sensor. No change in meter reading was detected. A slug of Chlorothane was also injected into the circuit ahead of the sensor. No change in meter reading was apparent.

The final test consisted of adding small quantities of water to the test circuit. No change in meter readings was evident.

Observations and conclusions drawn from the above laboratory tests are:

- The IKOR V/L Meter is capable of detecting entrained air in a moving hydraulic stream
- The IKOR V/L meter can detect hydraulic pump cavitation near the inlet port when the liquid changes partially into vapor and then collapses
- Null shift due to fluid temperature changes must be considered when using this instrument
- The V/L meter cannot detect AC fine test dust, chlorothane or small quantities of water in a moving MIL-H-5606 fluid stream.

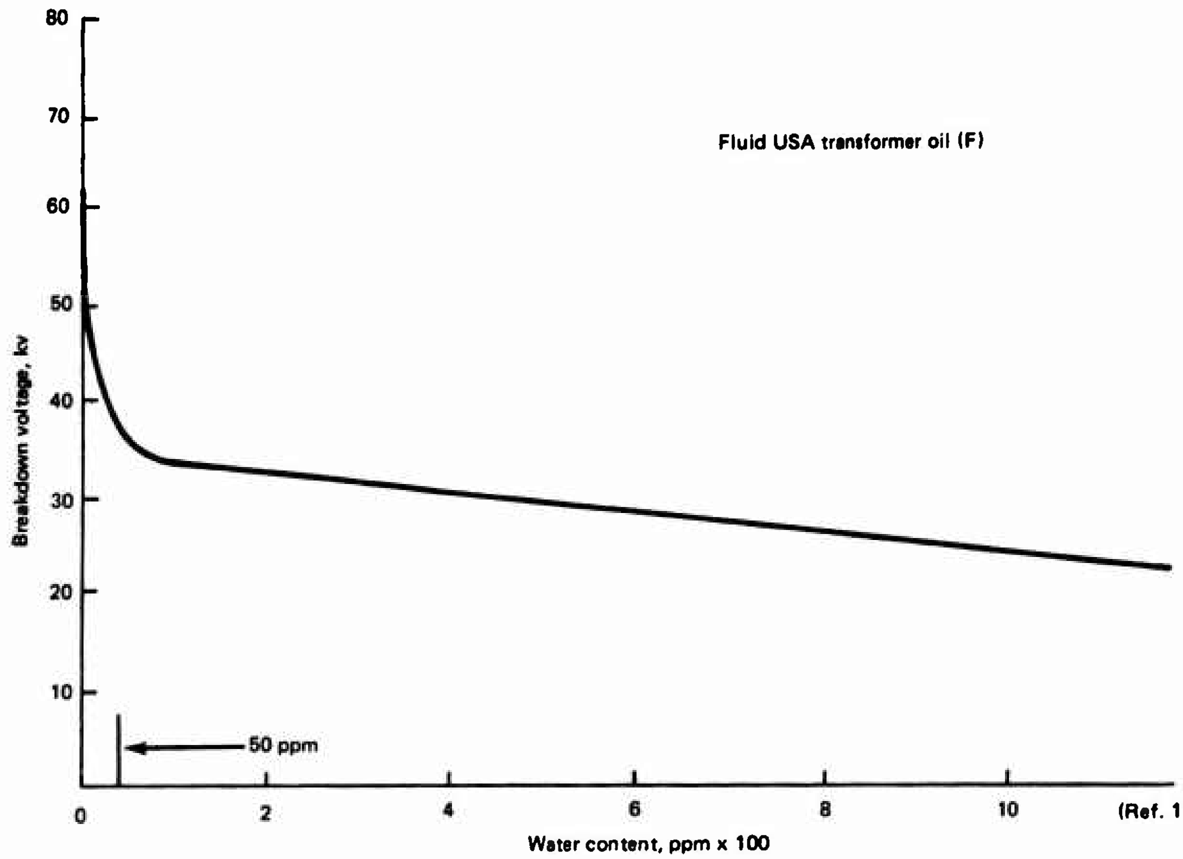
For information purposes, included are tables and figures showing physical and chemical data of hydraulic fluids and solvents. For comparison purposes, Table 9 lists some physical properties of MIL-H-5606 and MIL-H-83282 fluids.

Figure 43 is a graph showing the influence of moisture on dielectric strength of USA transformer oil (F). (Ref. 11) It is evident that the breakdown voltage changes drastically from 0 to approximately 50 ppm after which it remains almost constant. This type of test was not conducted on MIL-H-5606 due to the lack of suitable equipment.

TABLE 9. HYDRAULIC FLUIDS

Fluid	Pour point	Flash point	Acid no.	Viscosity, C/S	Solid contaminant - particles, max	Water max, ppm
MIL-H-5606 Hydraulic fluid petroleum base	-75°F	200°F	0.20 max	5.0 @ 210° F min 14.0 @ 100° F min 500 @ -40° F min 3000 @ -65° F max	5 - 15u 2500 16-25 1000 26-50 250 51-100 25 over 100	100
MIL-H-83282 Hydraulic fluid, synthetic hydro-carbon base fire resistant	-65°F	400°F	0.10 max	1.0 @ 400° F min 3.5 @ 2.10° F min 14.0 @ 100° F min 2200 @ -40° F max	5 - 15u 5000 16-25 1000 26-50 250 51-100 50 over 100	100

(Ref. 13 & 14)



(Ref. 11)

Figure 43. Influence of moisture on dielectric strength.

Table 10 lists the chemical properties of a number of solvents sometimes inadvertently used in cleaning lines and components of a hydraulic system. Figure 44 is a list of the fluid properties of MIL-H-5606 oil.

2.4.1.3 Effect of Water and Water + Freon in Mil-H-5606 on 1100 Series Low Carbon Steel

Three samples were prepared by Plant 10 Quality Control Laboratory, At Grumman, at the beginning of the HYCOS Program. The samples consisted of vials partially filled with hydraulic oil (Mil-H-5606) and contained a piece of 1100 series low carbon steel.

- Vial A - was left dry (no fluid additions)
- Vial B - contained small amounts of water >300 ppm
- Vial C - contained small amounts of water plus freon (free water & freon)

The capped samples were left standing at atmospheric conditions for a period of five months after which they were sent to the Q/A lab for analysis. The Lab photographed both the fluid and the test specimens (Figure 45).

The photographs show practically no change in the fluid or specimen with the dry hydraulic oil. No evidence of corrosion was evident on the test specimen. The second wet specimen (MIL-H-5606 over-saturated with water) showed extensive corrosion. Oxides in the form of rust was evident in the fluid sample. The third specimen bottle contained water and freon. As evident by the photograph, corrosion was most severe in this latter case, indicating that corrosion takes place in a hydraulic system with free water and is accelerated with the presence of traces of freon. This occurrence does not necessarily require extended fluid movement or high operating temperatures.

Although the above tests were conducted with oversaturated solutions of liquid contaminants, they give some evidence of what can happen.

Halogenated solvents have been used in the past for final component cleaning and rinsing operations. As a result, these materials 1, 1, 1, - trichloroethane and 1, 1, 2 trichloro or 1, 2, 2 triflouroethane, have appeared in lubricants and hydraulic fluids. (Ref. 9) Since traces of water are inherent in all hydraulic fluids, the combination of these two fluids may be responsible for corrosion occuring in some hydraulic systems. Limited or restricted use of these halogenated solvents should minimize the corrosion problem. Another alternative is to consider the use of more corrosion resistant materials in hydraulic systems or provide suitable corrosion resistant coatings.

Detecting the presence of minute traces of halogenated solvents in MIL-H-5606 is not easily accomplished. Two methods: X-Ray fluorescent and microcolumetric are compared using various sample concentrations. (Ref. 10)

Some current hydraulic system designs did not specify acceptable chlorine contamination limits since it was not a requirement. There is a tendency, however, to consider establishing acceptable values in an effort to control corrosion in specific aircraft.

2.4.1.4 Chlorine Detection Methods

Several methods of detecting traces of chlorine in hydraulic oils have evolved during the years. As defined in AIR 1416, they are listed briefly (Ref. 12):

X-Ray Fluorescence Spectroscopy Method

The method relies upon the establishment of a linear standard calibration curve. A series of chlorine standards is made by dilution of a 1000 ppm stock chlorine containing solution. This initial standard solution is prepared from a known chloro-organic compound and a stock sample of phosphate ester fluid which is known to contain less than 50 ppm chlorine. The intensity is measured on the chlorine K line for each standard. An absolute background intensity is measured and subtracted from the measured intensities for both standards and unknowns. A calibration curve of peak intensity versus concentration of chlorine added is then plotted. The intercept on the negative concentration axis (abscissa) represents the concentration of chlorine in the stock phosphate ester fluid, while the intercept on the intensity axis (ordinate) represents the intensity due to this determined chlorine concentration. The chlorine content of an unknown is then easily found from the intensity by simple proportion.

Microcoulemetric Procedure

Using standard microcoulometric technique, liquid samples are injected into a flowing stream of gas containing about 80% vol. percent oxygen and 20 percent argon.

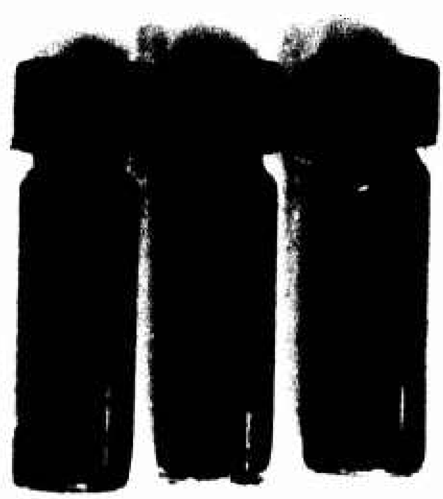
TABLE 10. SOLVENTS.

Fluid	Specific gravity	Free chlorene	Cleanliness	Water content	Boiling point °F	Purity, %	Chloride ion, ppm	Acid number, max	Particulate matter/100 ml.	Flash point (closed cup)	Sulfuric acid absoration max
MIL-T-7003 Trichloroethylene (stabilized decreasing)	1.454/1.476	None	Complete evaporation on filter paper	Fluid may be cooled to 23°F without cloud formation	–	–	–	–	–	–	
Mil-C-81302 Trichlorotriflouro-ethane	–	–	–								
• Type I				10ppm	117.6	99.9	0.01	0.003	25 to 100u-100 over 100u-10	–	–
• Type II				10 ppm	117.6	99.8	0.01	0.003	25 to 100u-100 over 100u-10	–	–
MIL-T-P7602 Trichloroethylene oxygen propellant compatable	1.450/1.470	–	–	Cloud point 14°F max	186.8	–	–	0.001	–	–	–
MIL-T-31533A Trichloroethane (methylchloroform) inhibited (1-1-1)	1.300/1.327	None	–	100 ppm	158	93	–	0.020	–	–	–
P-D-680 dry Cleaning solvent	–	–			300	98.5	–	–	–	100%	5
OT-236b Tetrachloroethylene (perchloroethylene) technical	1.620/1.630	–	–	–	122	–	–	–	0.01% max distiliate residue	–	–

MIL-H-5606

- Flash Point —— 200-225° F
- Fire point —— 255° F
- Auto ignition temperature —— 475° F
- Vapor pressure —— 0.445 at 160°
- Coefficient of expansion —— 4.6×10^{-4} /° F
- Specific gravity —— 0.83 at 60° F
- Pour point —— -75° F
- Bulk Modulus —— 320,000 at 160° F
- Color —— Red
- Thermal conductivity —— 0.077 at 160° F
- Specific heat —— 0.506 at 160° F

Figure 44. Hydraulic fluid properties (Ref. 4).



a. Dry b. Wet water c. Water & freon

Figure 45. 1100 Series low carbon steel.

The gas and sample flow through a combustion tube maintained at approximately 800° C. The chlorine is converted to chloride and oxy-chloride which then flow into a titration cell where they react with silver ions present. The silver ions thus consumed are coulometrically replaced. The current required to replace the silver ions is a measure of the chlorine content of the injected sample.

The microcoulometer can be utilized precisely in ranges of 0 to 500 parts total chlorine per million. It is expedient to dilute higher chlorine level samples with standard new fluid prior to analysis.

Infrared Procedure

The basic principle underlying this infrared method involves the volatilization of a relatively low boiling point contaminant from a relatively non-volatile fluid and the analysis of the vapor phase. The method provides a quantitative measure of liquid phase concentration due to the application of Henry's Law. The procedure utilized is as follows: A measured sample of fluid (25 ml) is transferred to a 160 ml Pyrex container which is fitted with a two-way stopcock. The container is placed in a boiling water bath for 5 minutes, attached to an evacuated 100 ml IR gas cell and the cell and fluid container brought to equilibrium. This results in a vapor sample at lower than ambient pressure. An IR spectrum is then run to compare peak locations for qualitative identification and/or to measure peak height for quantification. A calibration curve is made up using measured amounts of standard contaminants in the base fluid. The method is dependent on Henry's Law and can be applied to single or mixed contaminants. If care is taken to utilize the same parameters for analyzing an unknown as for the standards, it becomes unnecessary to accurately measure container volumes or pressure, comparison alone under controlled conditions being a sufficient criterion.

Gas Chromatography

The sample is chromatographed on a column containing silicone oil as a liquid phase to separate the components of interest. A dual column, dual detector system is required since the oven temperature is programmed during the analysis. The chromatogram generated from the sample is compared directly with a reference chromatogram for an equal amount of standard hydraulic fluid. The concentration of contaminant is determined by comparing the peak area ratio of the contaminant versus a standard hydraulic fluid component with the same ratio for a reference sample containing a known concentration of the contaminant. Thus, a component of the fluid is used essentially as an internal standard rather than directly comparing contaminant peak areas in the sample and reference mixture since the ability to reproducibly inject a sample is limited for the small amount injected.

Chloride Ion Determination

The amount of chloride ion present may be determined by aqueous extraction and silver nitrate turbidimetry which is reported sensitive to approximately 0.1 ppm.

Another procedure is based on the potentiometric titration of the chloride ion with silver nitrate solution. After acidification of the sample with sulfuric acid and dilution with acetone, the chlorides are titrated with 0.005N silver nitrate solution. As little as 0.1 ppm chloride ion can be measured.

Lab Procedure for Chlorine Determination in MIL-H-5606

From Paul Storms, Exon Research Labs, Linden, N.J.
(201) 474-2611 Referred to by John Clarke

Procedure (Qualitative)

1. Extract approximately 100 ml sample of MIL-H-5606 from system.
2. Add vial of sodium biphenyl to fluid.
3. Shake into a homogenous mixture.
4. Place in separatory funnel.
5. Kill excess sodium biphenyl with addition of nitric acid & shake.
6. Aqueus layer will settle to bottom.
7. Drain off aqueus layer.
8. Add silver nitrate - If white precipitate forms, chlorine is present.

Mr. Storms also suggested that we contact Mr. Bill Dudek for procedure of water determination in jet fuels which might have applicability to water determination in MIL-H-5606.

Bill Dudek
54 (201) 474-2781

System probably uses cobolt chlorine principal which changes color from blue to pink with presence of water.

Kits of sodium biphenyl can be purchased from:

South Western Analytical Chemical

P. O. Box 485

Austin, Texas 78767

Kit consists of 20 vials and costs approximately 20.00 per box.

2.4.2 Sampling Valves

Sampling valves provide easy access to the fluid used in the hydraulic system. When they are strategically placed, they can be used to detect and verify component failures. Sampling valves can be incorporated into specific hydraulic manifolds during the design phase but they cannot be readily relocated within the system without adding potential leak paths.

One manufacturer, Aircraft Porous Media, Inc., has developed a Multicator © which is a combination differential pressure indicator and sampling valve. This approach is a step in the proper direction since it makes available potential sampling points without adding significant complexity. Figure 46 shows an APM AD-A516-2 Multicator also installed in a hogged out F-14A hydraulic manifold.

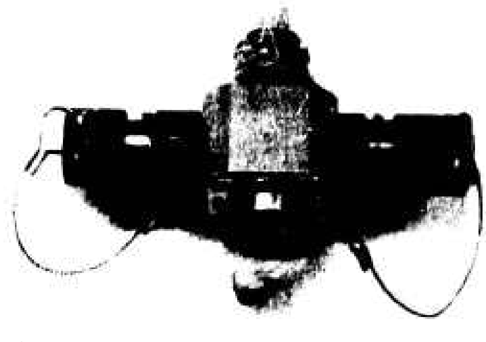
The HYCOS system would use sampling valves at the following locations:

- Hydraulic pump case drain filter (upstream side)
- Main system return filter (also upstream side).

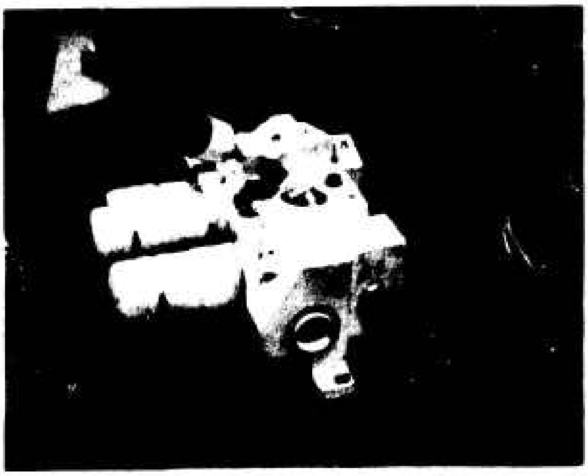
Should the need arise, other locations would be considered for specific systems.

2.4.3 Fiber Optics

Fiber optics is the channeling of light through a rod or fiber of either glass or plastic material. Figure 47 shows how light enters the end of a rod or fiber and is reflected off the sheath-core boundry. It is then reflected throughout the core, traveling in zig-zag fashion until it reaches the end of the core.



a. Combined differential pressure indicator and fluid sampling valve.



b. Multicator installed in a hogged out F-14A filter manifold.

Figure 46. Aircraft Porous Media AD-A516-2 Multicator.©

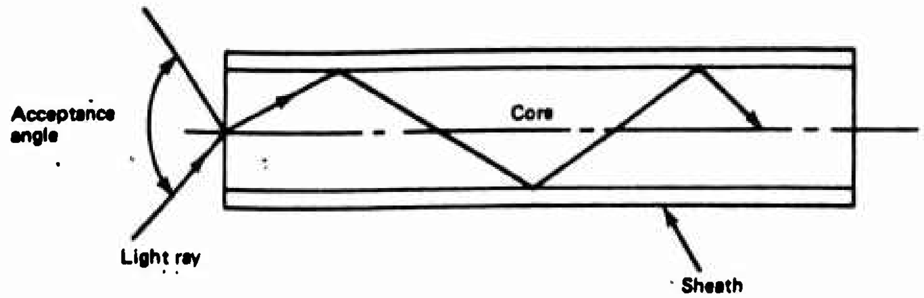


Figure 47. Light path through an optical fiber.

The application of fiber optics has expanded into many fields of science and industry. Included are such areas as:

- Medical
- Aeronautical
- Industrial
- Automotive
- Communication
- Research.

The fiber optics used in these areas are divided into two general types, image transmission or coherent, and non-image transmission or non-coherent. The image transmission cable is used in those fields where the output from the cable has to be an exact image of the input. This of course, requires that the fibers be oriented or aligned such that their location at the output end of the cable be identical to the input end. In addition, this type of cable may require viewing in areas where there is little or no light. For these cases, a cable construction is used in which there is an external layer of fibers that are separated from the coherent cable at the input end. As shown in Figure 48, these fibers are connected to a light source to illuminate the field of view (Ref. 15).

The non-image transmission or non-coherent cable, also known as a light guide or a light pipe, has random placement of its fibers. It's primary use is in communication systems. Here, electrical signals are converted to light signals which are transmitted to a remote unit through a fiber optics cable and then restored to an electrical signal in the remote unit. The light signal is generally produced by a light emitting diode (LED) located in the transmitter. Light is emitted when the diode is

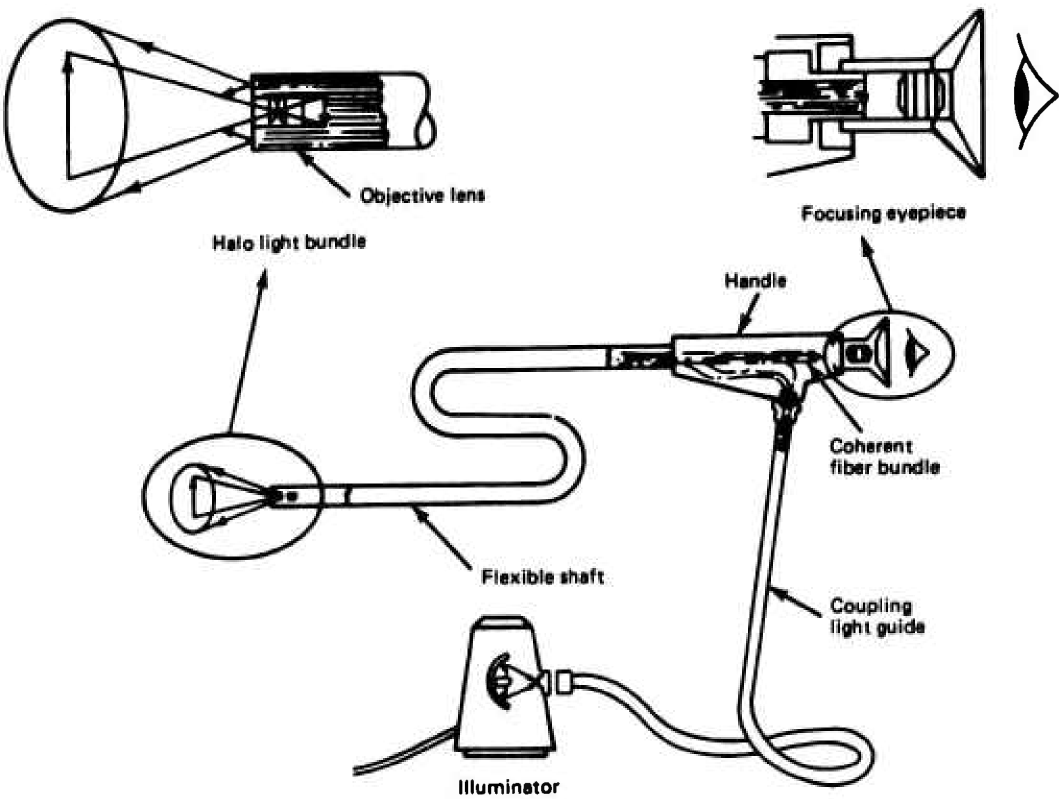


Figure 48. Schematic of an American Optical Fiberscope.

forward biased. At the receiving end, the light strikes a photodiode which converts the signal back to an electric impulse. The input signal need not always be electrical. For example, colored light can be transmitted by the cable to indicate whether a system or component is go or no-go by transmitting a green or red light.

Table 11 lists data for both glass and plastic fiber optics cable. Both types of cables have similar characteristics, the primary difference being the temperature limits of the two materials.

Figure 49 shows the transmissability of both plastic and glass fiber light guides as a function of wave length.

For the HYCOS program, the decision has been to use non-image forming or non-coherent cable. The transmission of alphanumeric figures would require the use of coherent cable which is more costly then non-coherent cable. Manufacturing techniques are such that the price of coherent cable rises rapidly in lengths above 15 feet. Much of the HYCOS information can be transmitted by white or colored light using non-coherent cable. In addition, the cable would be constructed from glass fibers because it can withstand higher temperatures than the plastic fibers. Although the bend radius for glass fiber cables is higher than the plastic fiber, it is still sufficiently small for most installations.

Fiber optics cables can be joined by screw type connectors manufactured by Cannon. They produce many style of connectors for joining single and multi-channel cables. Connectors are made with fiber optics contacts or with fiber optics and electrical contacts in the same shell.

A severed non-coherent type cable can be joined by inserting each end in a ferrule and filling it with epoxy. After the epoxy has set, the ends are ground and polished to a fine finish. When butted together, the cable will transmit a signal with little attenuation.

Possible applications for fiber optics in the HYCOS program include:

- Liquid sensing in a pneumatic bottle
- Measurement of fluid level in shock struts
- Dessicant saturation monitor.

TABLE 11. FIBER OPTIC PROPERTIES

Desig-nation	Manufac-turer	Material		Dimensions			Min bend	Temp limit, °F	Max transmittal (nanometer)
		Core	Jacket	Core OD, inch	Fiber OD	No. of strands	Radius in.		
PFX0715	Dupont	Polymethyl Methacrylate	Black polyethylene	0.075	0.0146	7	0.32	175	650 - 670
1110	Dupont	Polymethyl methacrylate	Polyethylene resin	0.087	0.010	16	0.32	175	650 - 670
LGM-2	American Optical	Glass	Polyvinyl chloride	0.062	0.003	500	0.625	220	600 - 700
102	Valtech	Glass	Polyvinyl chloride	0.125	0.002	4000	PVC = 0.50 Monocoil = 0.75	220	600 - 700

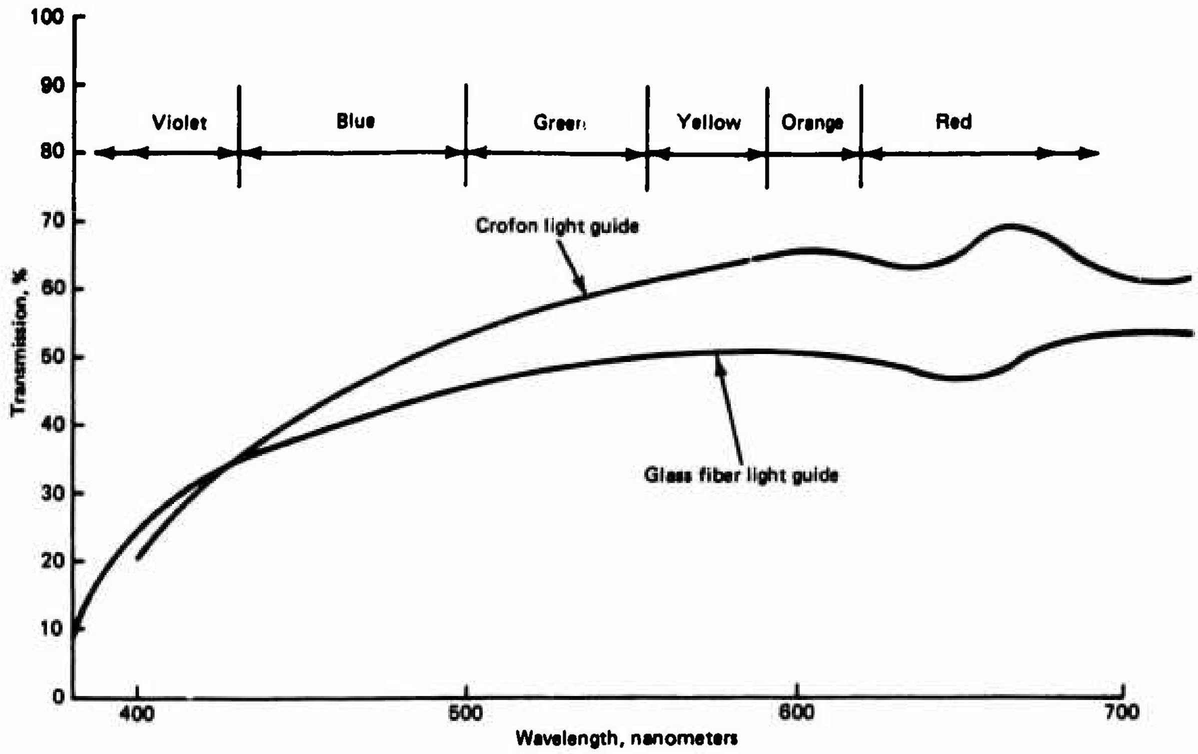


Figure 49. Spectral transmission vs wavelength at 4 feet.

2.4.4 Fluid Detection in Pneumatic Bottles

Background: Pneumatic Bottles are sometimes used as stored energy sources for emergency conditions. In cases as emergency gear blowdown, compressed nitrogen is directed to the door and gear actuating cylinders. During recycling, hydraulic fluid sometimes inadvertently enters the pneumatic system. This condition usually goes undetected unless the bottle is bled after charging. During normal pressurization, a pneumatic bottle could be partially filled with hydraulic oil and charged with nitrogen to the required level. Actuation of this system could possibly result in an incomplete gear or system extension cycle.

In order to detect the presence of hydraulic oil in pneumatic bottles, several methods have been considered.

- Float Gages - Not applicable to high pressure conditions and bottle configuration.
- Thermo Electric - Not suitable for pneumatic systems due to potential hazards involved.

- Hot Wire Probe - Possibly suitable for consideration. This system uses a heated platinum wire. With the presence of oil or moisture, temperature change is detected by a bridge circuit.
- Capacitance Gage - Senses changes in capacitance due to variation in dielectric constant of fluids. Temperature variation affects reference point.
- Ultrasonics - Could be used but support equipment required for this system is substantial.
- Photo Electric - Utilizes light transmission thru fiber optics - presence of oil would indicate on panel due to optical coupling with fluid presence,

Of all the candidates, the photo electric type appears to be the most promising and lends itself more readily to the HYCOS configuration. A typical pneumatic bottle installation is shown in Figure 50.

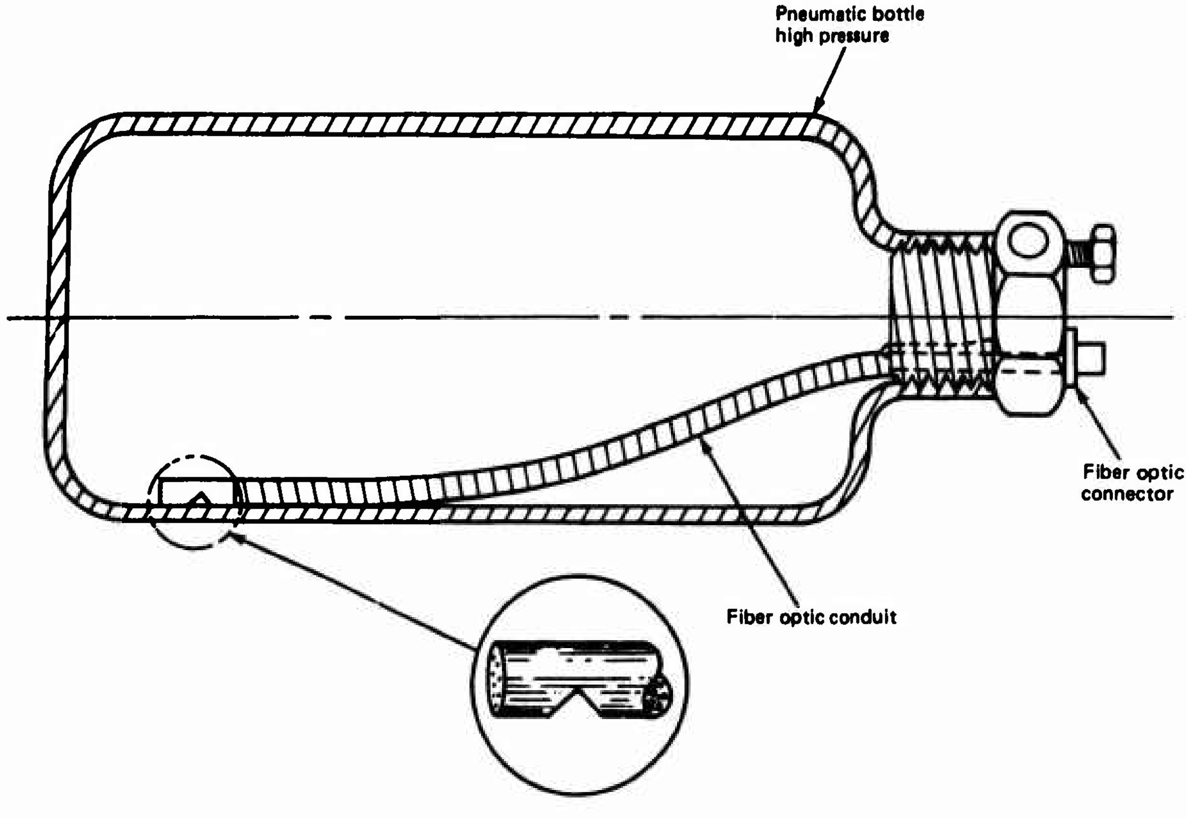


Figure 50. Liquid sensing in pneumatic bottle (concept).

2.4.5 Quiescent Flow Sensors

Quiescent flow sensors are devices which are placed on the pump discharge pressure line and in other critical areas of the hydraulic system. They monitor system quiescent flow at ground idle conditions in order to determine the efficiency of the hydraulic system.

$$E_S = \frac{Q_{max} - Q_L}{Q_{max}} \times 100\%$$

E_S varies between 90% to 95% in an efficient system. When E_S decreases to 85/80% this indicates that the system efficiency is degraded and that energy is being transformed into heat. The sensor also detects a component bypass out of limits in relation to the system demand at quiescent flow conditions. See Figure 51 for a graphical representation.

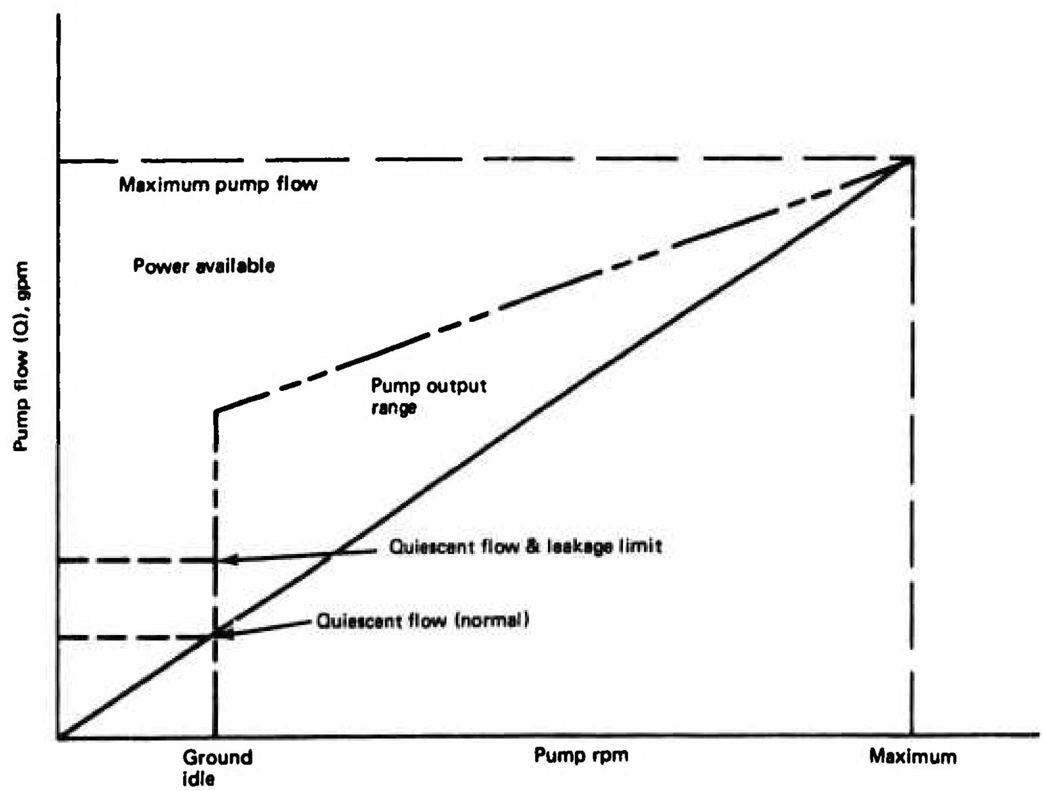


Figure 51. Quiescent flow determination limits (no power demand on system).

Quiescent flow conditions are defined as those existing when the system is pressurized and with no control system demands; i.e., the variable displacement pump compensates for total system leakage only. System leakage varies from aircraft to aircraft within a fixed tolerance band for the same system. Sensors must exhibit low pressure drops at rated flow and must not indicate during normal system operation when the demands can vary from quiescent to full flow. Sensor indication must be restricted to ground idle conditions only. This can be accomplished in several ways:

- Restraining indicator motion until a reading is desired
- Building in a time delay into this circuit.

Flow sensors must meet the component design and performance requirements of MIL-H-8775 as applicable. In addition, the potential failure mode must be such that it fails open and does not give erroneous indications.

System quiescent flow sensors may be placed directly in the pump discharge line as shown in Figure 52. The flow sensor should have a visual readout as well as an electrical indication. One type of unit is shown in Figure 52.

In order to minimize trouble shooting, it is desirable to locate additional sensors on the return side of the primary flight control actuators. This includes the stabilizer or elevator, flaperon or spoiler, and rudder. Should any of these sensors and the system quiescent flow sensor actuate simultaneously, this would indicate a major problem which requires immediate attention. Table 12 shows some of the maximum allowable quiescent flow leakage rates on typical aircraft.

Two types of flow sensors including measuring devices have been considered:

- Sharp edge orifice
- Venturi measuring section.

The Venturi measuring section exhibits better pressure recovery at the higher measuring flow values. See Figure 53 for a comparison.

Flow sensors with external visual indicators must be provided with a means of preventing actuation during normal system operation until the system is interrogated, otherwise erroneous indications may occur.

a. Aircraft Porous Media AC-A453-1 flow monitor

b. Flow monitor shown installed in F-14A hydraulic pump pressure line.

Figure 52. Aircraft Porous Media.

TABLE 12. QUIESCENT FLOW LEAKAGE RATES

Aircraft	Actuator	Leakage rate, gpm
E-2C	Aileron	0.26
	Elevator	0.20
	Rudder	0.19
A-6E	Flaperon	0.26
	Elevator	0.26
	Rudder	0.26
EA-6B	Flaperon	0.26
	Elevator	0.26
	Rudder	0.26
F-14	Rudder	0.17
	Stabilizer	0.40
	Midspoiler	0.34
	Outboard spoiler	0.34
	Inboard spoiler	0.34
	Series input	0.23

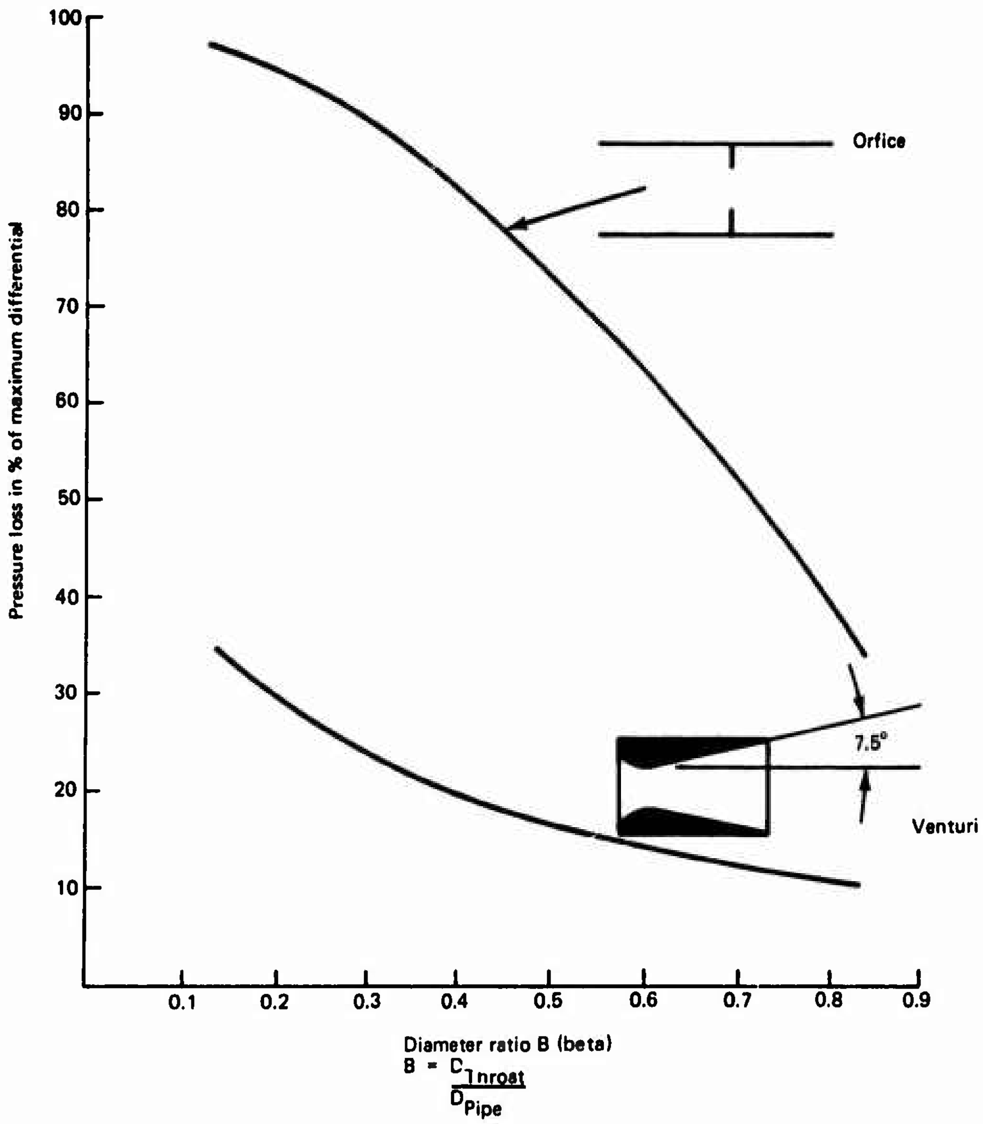


Figure 53. Pressure loss comparision (Ref. 7).

Since the flow sensors are located in critical positions on the hydraulic circuit, they must cycle every time an input is placed into the control actuator, consequently they require extended service life.

Shunt flow sensors are preferred in place of the non-shunt type, since they have the ability to handle excess momentary flow. This may occur with a pump block liftoff or normal demand from a flight control component.

Figure 54 shows a sharp edge orifice type flowmeter used on some commercial aircraft. The flowmeter has a 0-14VAC output with a 115V 400~single phase input. No provision is made for visual indication.

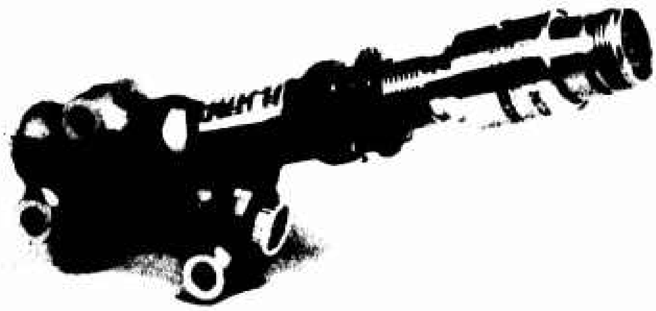


Figure 54. The Arkwin Quiescent Flowmeter - Model 7A204.

2.4.6 Elapsed Time Meters

Elapsed Time Meters are an essential part of the HYCOS System. The meter would form part of the readout panel and could be used in the following categories:

- Indicate hydraulic system operating time
- Utilized in determining the hours a component has accumulated since its installation and removal
- Verification that system pressure switch is operational.

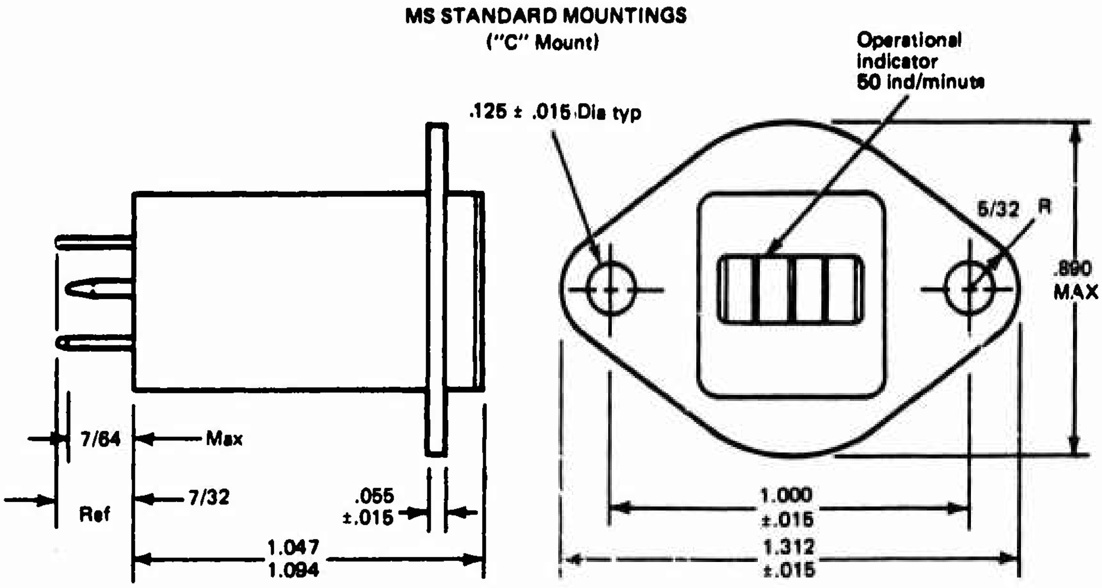
The elapsed time meter would operate when hydraulic system pressure is available (Flight or utility) and when electrical power 115VAC 400 ~ or 28VDC is on the line.

Elapsed time meters conforming to MIL-M-7793 would be suitable. As an example, MS27650 defines a 26V single phase 400 cycle totalizing time meter. See Figure 55.

Size - 1.06 x 1.04 x 0.50

Weight - 0.7 oz max

Current - 60 M.A. max



Product conformance to MIL-M-7793D and MS17322, MS26751 or MS27650.

Temperature range	- 65 C to + 125 C operating
Shock	MIL-STD-202, method 205 Condition C to an acceleration of 50G, 11MS (test equipment per method 202)
Vibration	MIL-STD-202, Method 204 Condition D
Casing	Inert atmosphere hermetically sealed with hook wire terminals – lusterless black unless otherwise specified.
Accuracy	0.1% at 400 Hz
Numeral color	White on black background; tenths of hours red on white background
Numeral size	0.035" x 0.078"

Figure 55. Military specifications and data.

2.4.7 Thermal Limit Sensors

Thermal limit sensors are used to indicate an over-temperature condition. They are located in various parts of the hydraulic system and measure fluid condition.

Several areas which justify temperature limit monitoring are:

- Pump case drain fluid
- Hydraulic backup package fluid
- Spoiler hydraulic fluid
- Main relief valve fluid flow (bypass).

2.4.7.1 Pump Case Drain Flow Temperature

Pump case drain flow temperature is an indication of the pumps operating efficiency. When the temperature is excessive, it can be used to signal a degradable mode of energy transfer and possible impending pump failure.

The type of thermal limit sensor would be one which is only manually resettable once it has actuated. In addition, it would close an electrical contact to indicate at the readout panel. Pump case drain flow over-temperature limits would be higher than the 275° allowed for Type II hydraulic systems.

Figure 56 shows a possible high response manually resettable thermal switch concept.

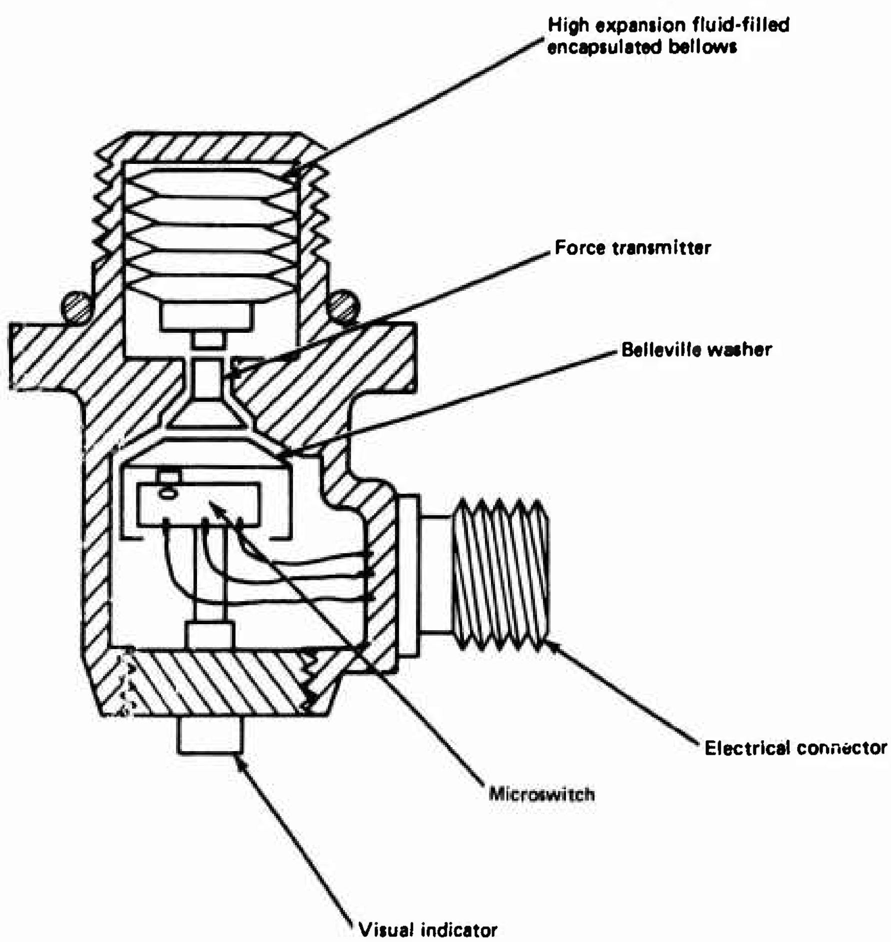


Figure 56. Thermal switch concept.

2.4.7.2 Hydraulic Backup Package Temperature Switch

An over-temperature indication in the hydraulic backup package is an invaluable tool in determining whether an abnormal condition exists in the emergency package. When used on the ground for supplying hydraulic power, it can be used to interrupt electrical power due to prolonged or extended use.

2.4.7.3 Spoiler Hydraulic Package Over-Temperature Sensor

The application of this temperature sensor is simular to the one used on the hydraulic backup package. Operation of the over-temperature switch would not affect package performance.

2.4.7.4 Main Relief Valve Temperature Sensor

When a faulty (leaking) relief valve is bypassing below its normal cracking value, excessive fluid temperature is generated due to high restriction and high pressure differential. This condition converts evergy into heat which is detected by the thermal sensor. The type of switch would be similar to the previous types. Table 13 shows some typical thermal switch applications.

Selection of main relief valve thermal setting would be dependent on system design. Figure 57 shows theoretical heat generated vs Δ P curves various flows.

2.5 HYCOS DISPLAY (READOUT)

The Hycos Display has been configured into the major function categories in an effort to readily pinpoint a malfunction or out-of-limit component. Figures 58 through 67 show possible malfunction displays. A display is broken down into the following components:

- Power Generation
- Fluid Supply and Condition
- Filter Condition
- Quiescent Flow (System Efficiency)
- Relief Valve (Failure Detection)
- Control Surfaces Interface Condition
- Strut Condition
- Pneumatic Bottle Pressures
- Accumulator Precharge
- Test Circuits.

TABLE 13. THERMAL LIMIT SWITCH APPLICATIONS

Name	Grumman P/N	Vendor P/N	Temperature Limits
Pump case drain Flow temperature	A51H9008	ABEX 65270	300°F max
Hydraulic backup Package fluid temperature	A51DCVBH002A	ABEX 53022-01 5322201	190 ± 10°F on 150°F min off
Spoiler hydraulic Package fluid temperature	A51DCVBH004	Vickers PPEV3-11	275 ± 15°F on 245 ± 10°F off
Pump, hydraulic Main engine driven	A51H9008	ABEX 65270	300°F max

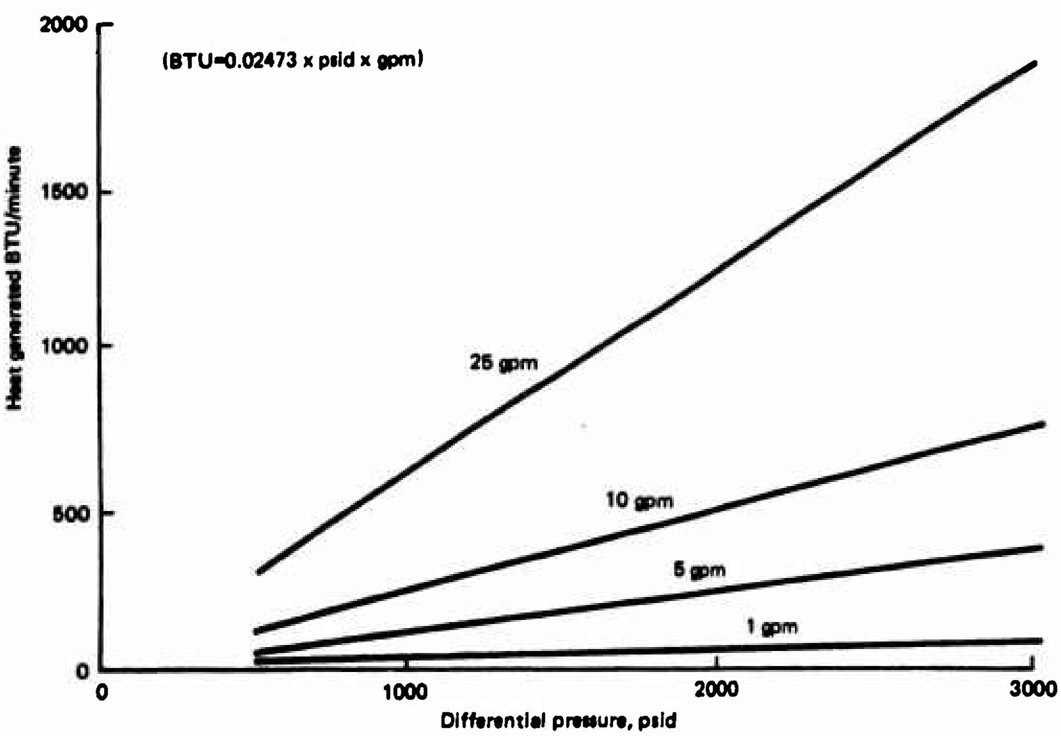


Figure 57. Plot of heat generated vs DP at various flows.

Power generation reflects the condition of the pumps which obviously effects system performance. A degrading pump would be picked up by this subblock. In some cases, several red light emitting diodes would illuminate, indicating a specific failure mode. This category covers all power generating equipment (Individual Pumps). Fluid Supply and Condition subblock reflects the status of the reservoir and indirectly the system, i.e., if small external system leak developed, level would drop and be reflected on panel; in addition, the reservoir over-temperature LED would probably illuminate. If reservoir pressurization is lost, the press LED would illuminate.

Desiccants used to dry pneumatically pressurized reservoirs sometimes are used beyond their useful life. An indication on the panel would turn a pinkish red.

The filter subpanel is primarily a maintenance function item. They would indicate when a filter element has reached the end of its useful life. The indicator is a function of differential pressure.

Table 14 illustrates the sequence of operation in using the HYCOS system. It indicates the type of signal generated by the various sensors and the significance of these signals.

In order to miniaturize the display panel, light emitting diodes (LED) of one color (red) are used for the principle display indicators. Light emitting diodes were selected for the following reasons:

- Small size (approx 0.25 in. dia)
- Develops monochromatic light
- High reliability (100,000 hr est life)
- High vibration & shock tolerance
- Low heat generation
- Low power consumption (1 to 5 mw)
- Low voltage requirements (1 to 5 VDC)
- Low cost
- Acceptable temperature limits (-50 to 300°F)
- Easily replaced.

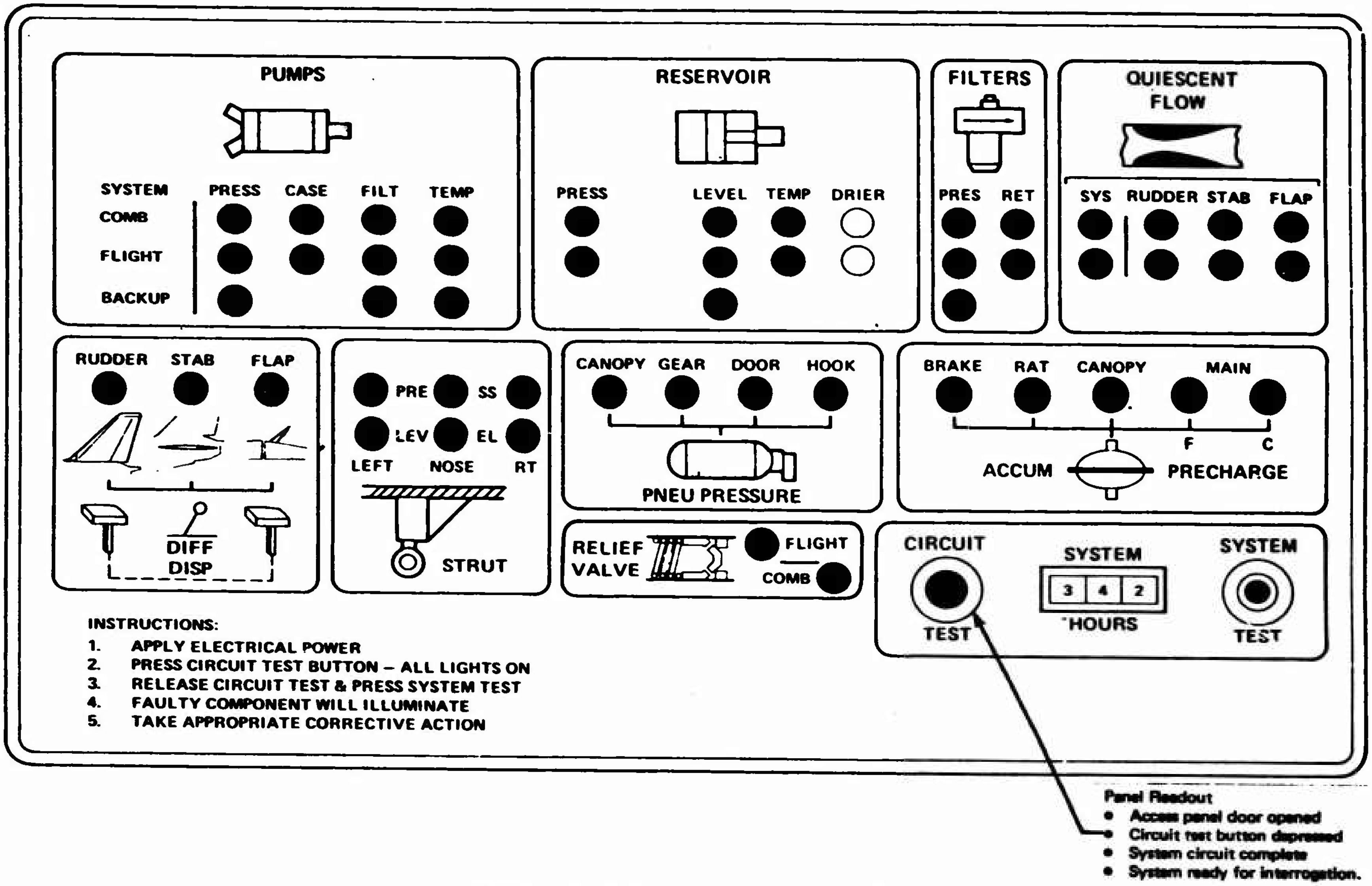
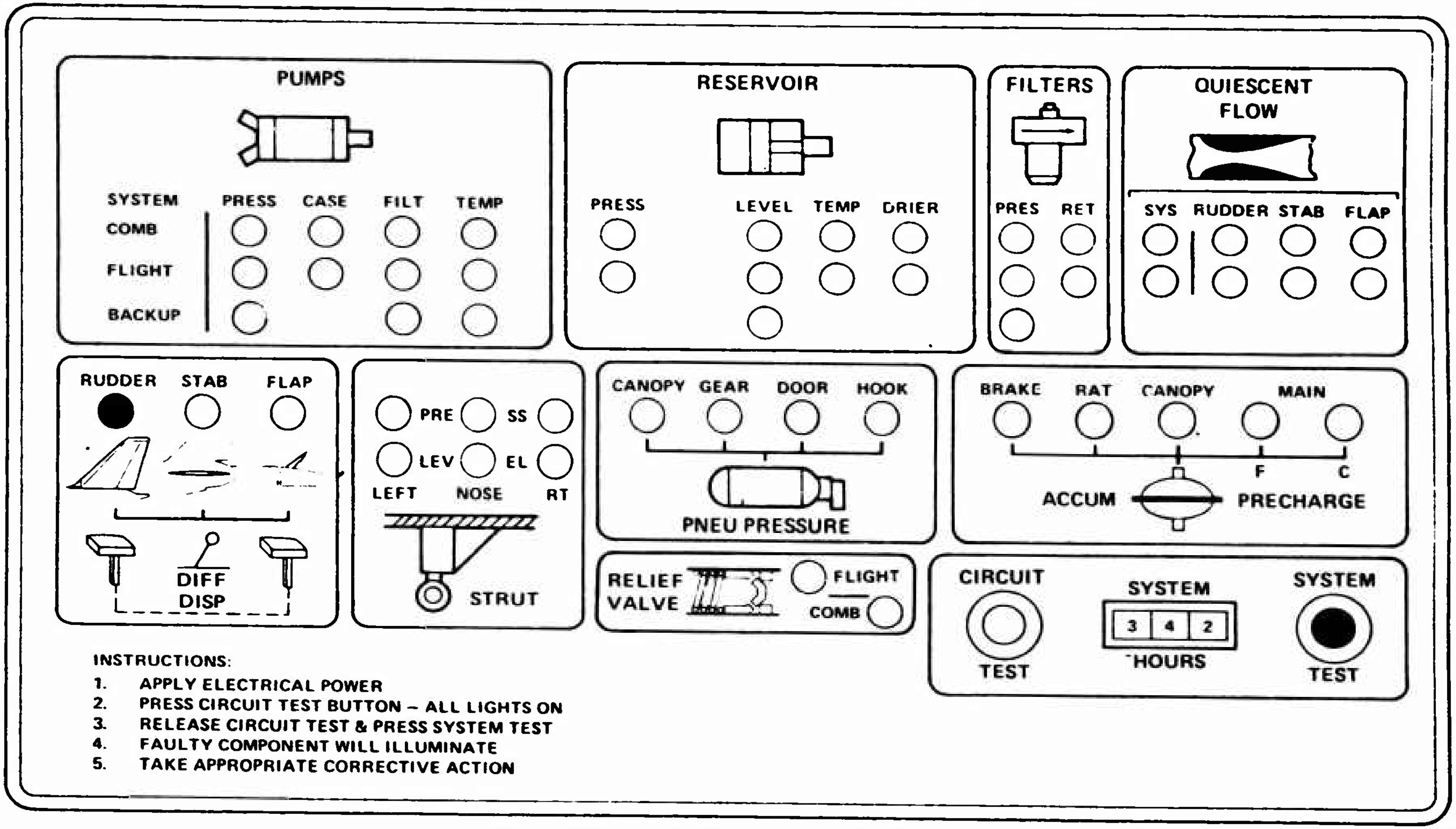
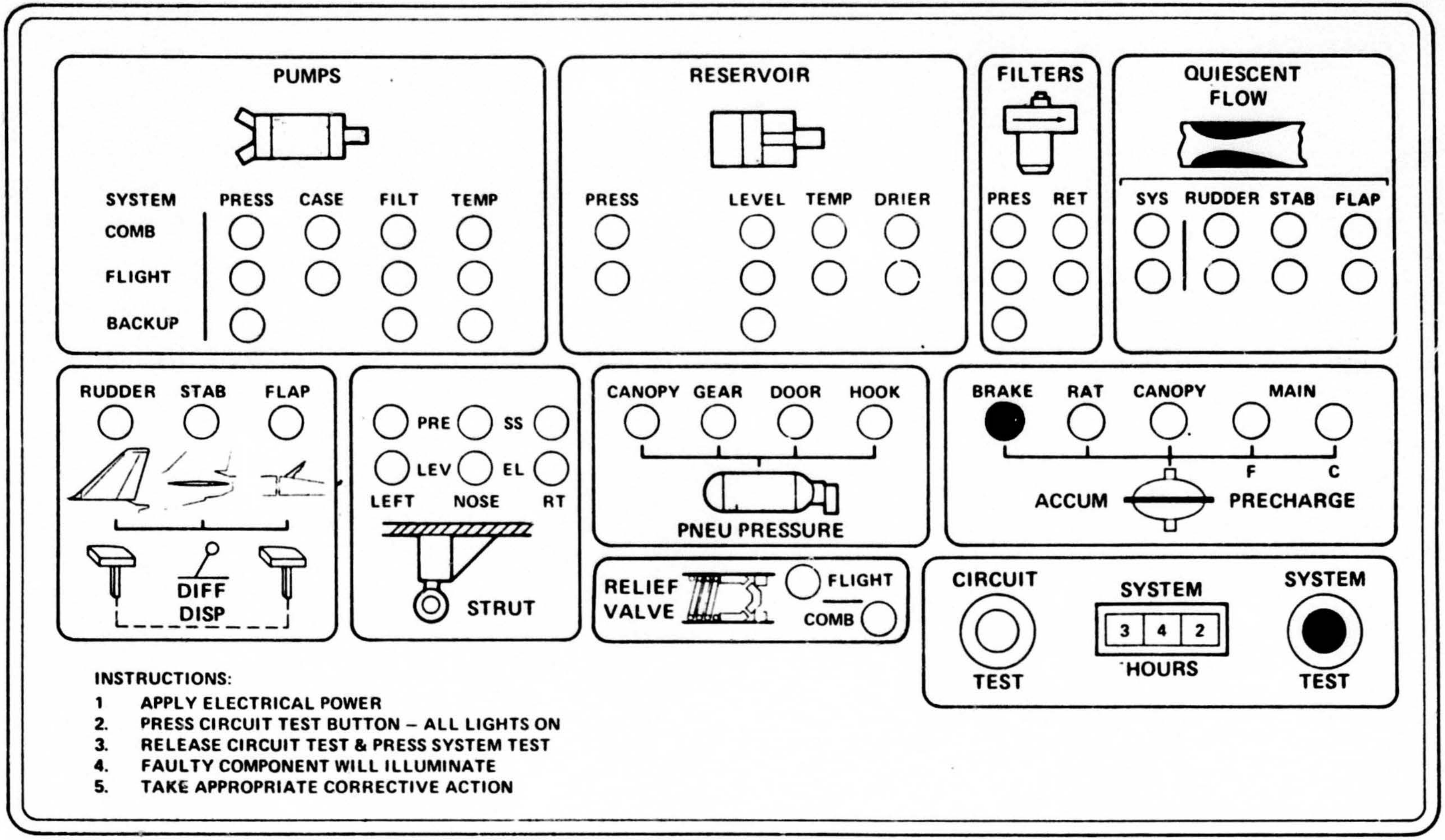


Figure 58. HYCOS display (readout).



Panel Readout
- Engine pumps turning
- Access doors opened
- System test button depressed
- Indicates discontinuity between rudder pedals and rudder actuator.

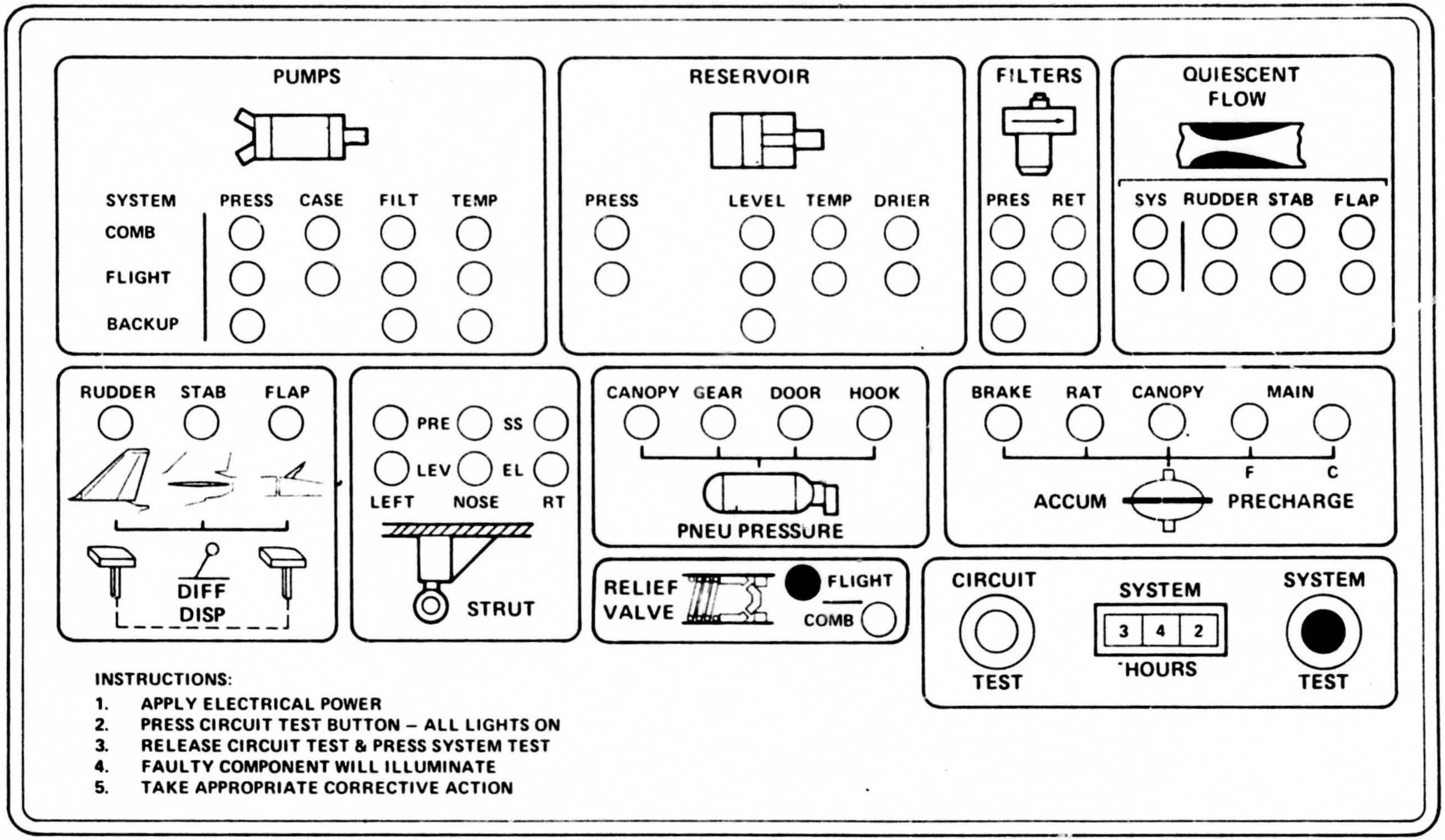
Figure 59. HYCOS display (readout).



Panel Readout

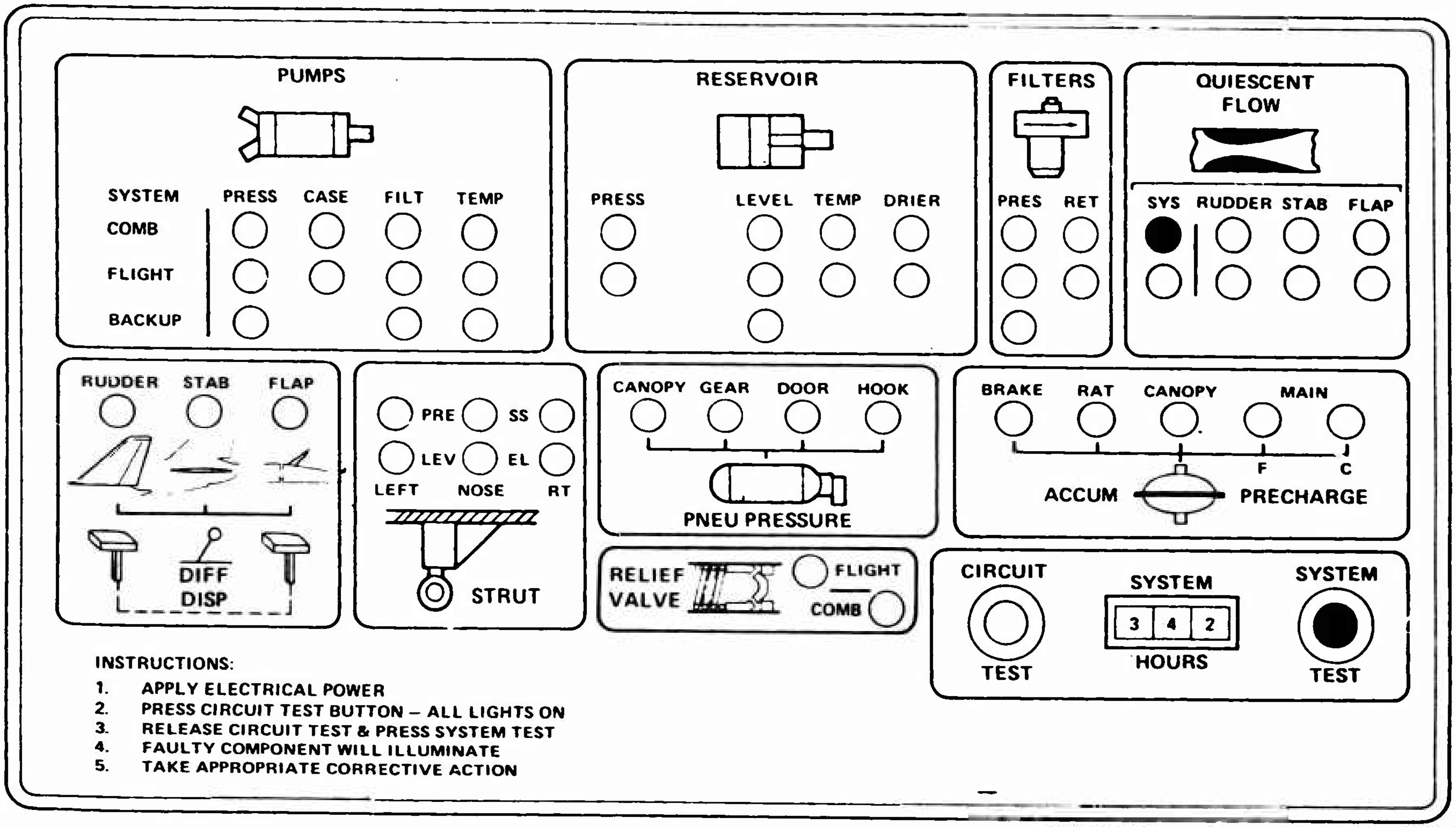
- **Access panel opened**
- **Deplete brake system pressure**
- **Brake accumulator precharge low.**

Figure 60. HYCOS display (readout).



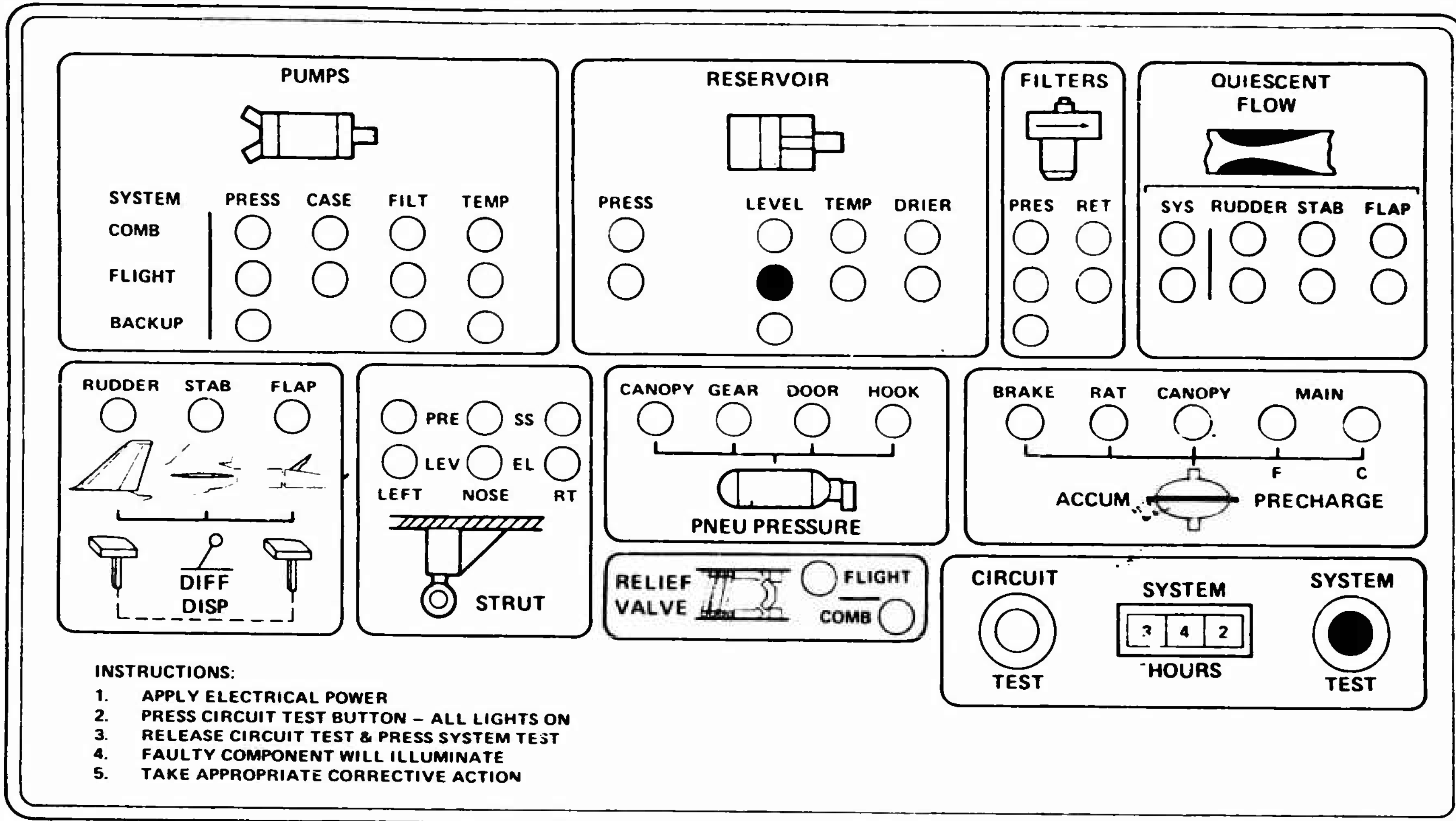
Panel Readout
- Engine pumps turning
- Access door opened
- System test button depressed
- Flight system relief valve bypassing.

Figure 61. HYCOS display (readout).



Panel Readout
- Engine pumps turning
- Access door opened
- System test button depressed
- No inputs to control or utility circuits
- Indicates excessive system or component leakage.

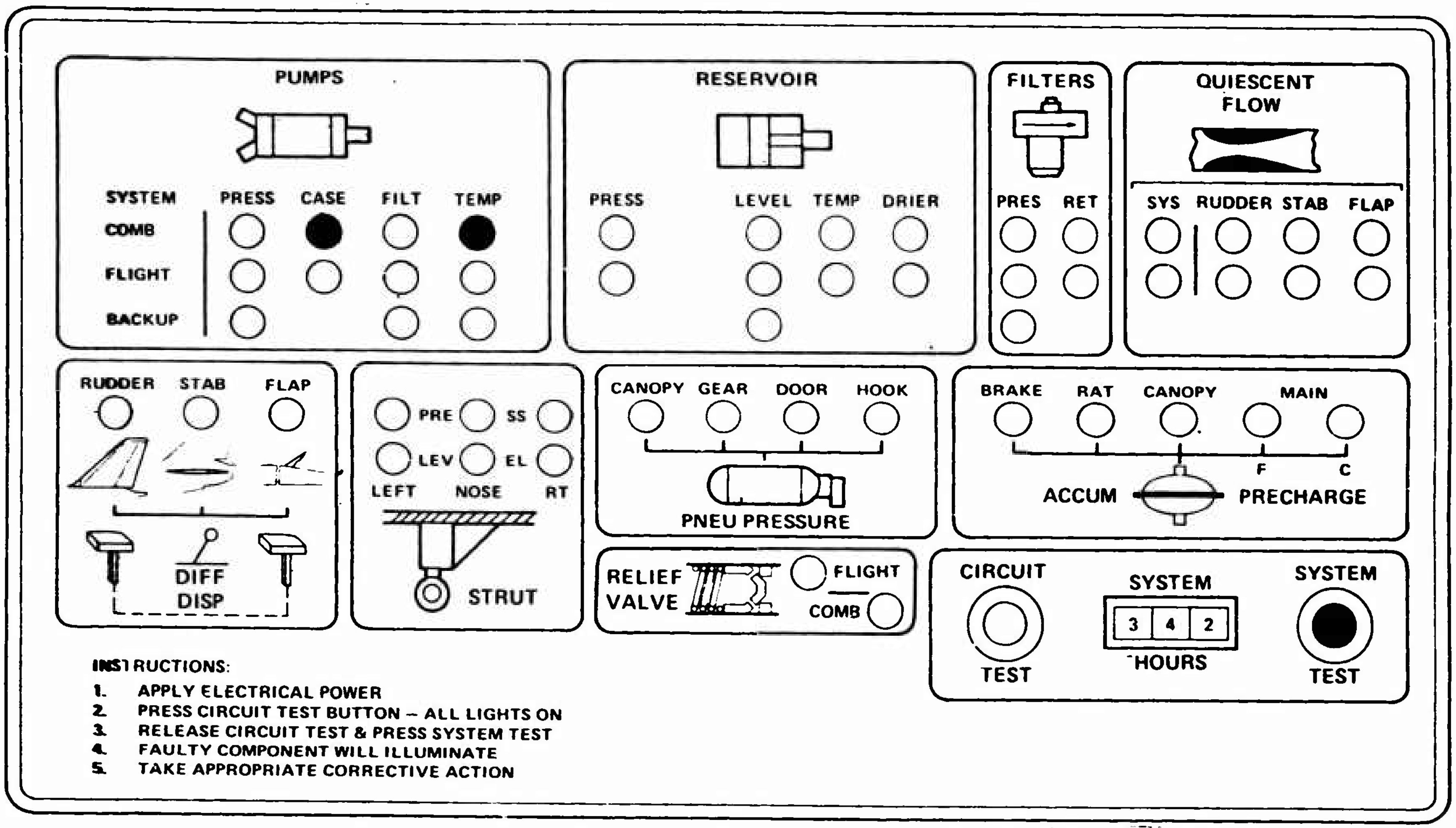
Figure 62. HYCOS display (readout).



Panel Readout

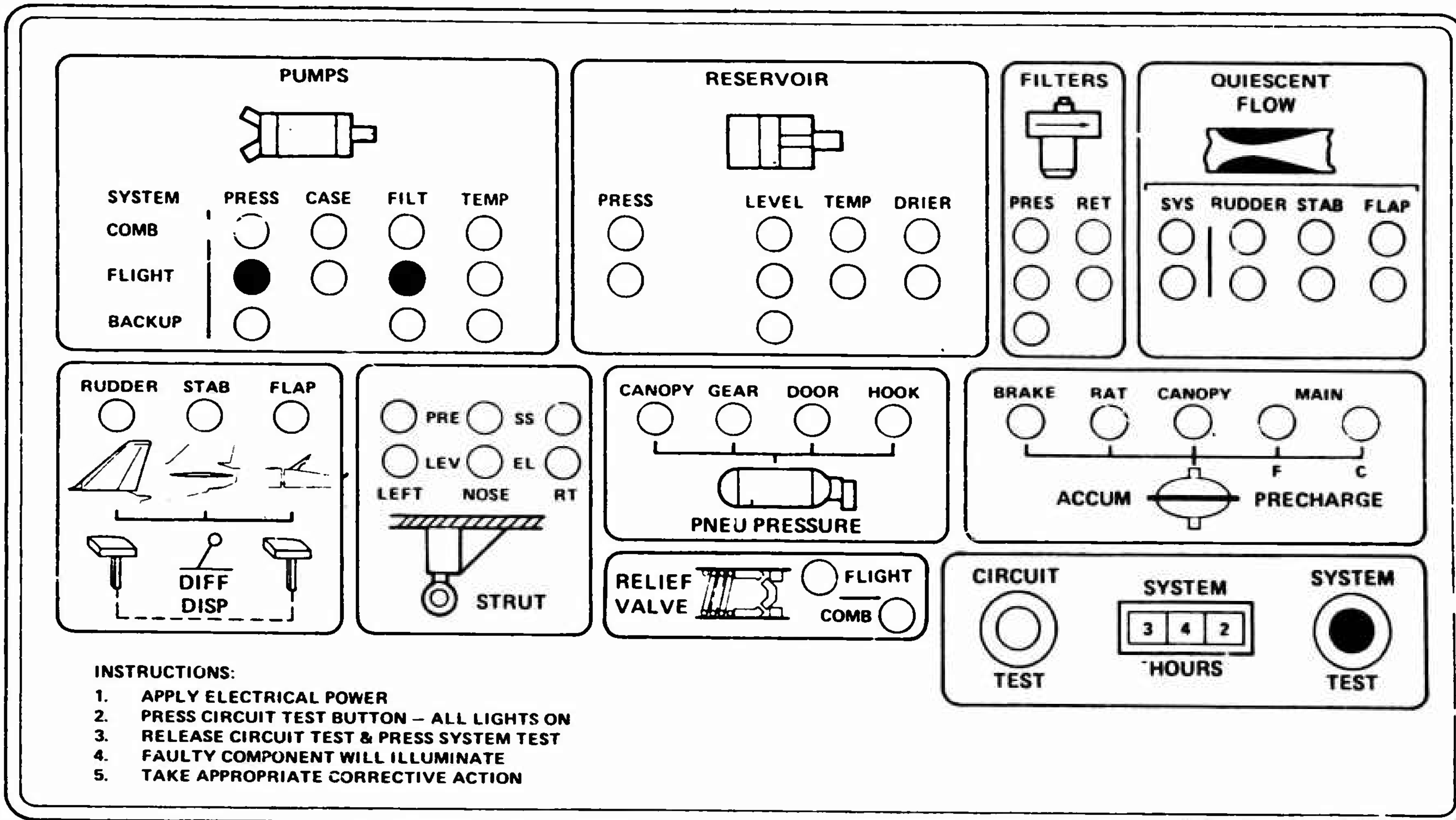
- Engine pumps turning
- Access doors opened
- System test button depressed
- Indicates low fluid level in flight system reservoir.

Figure 63. HYCOS display (readout).



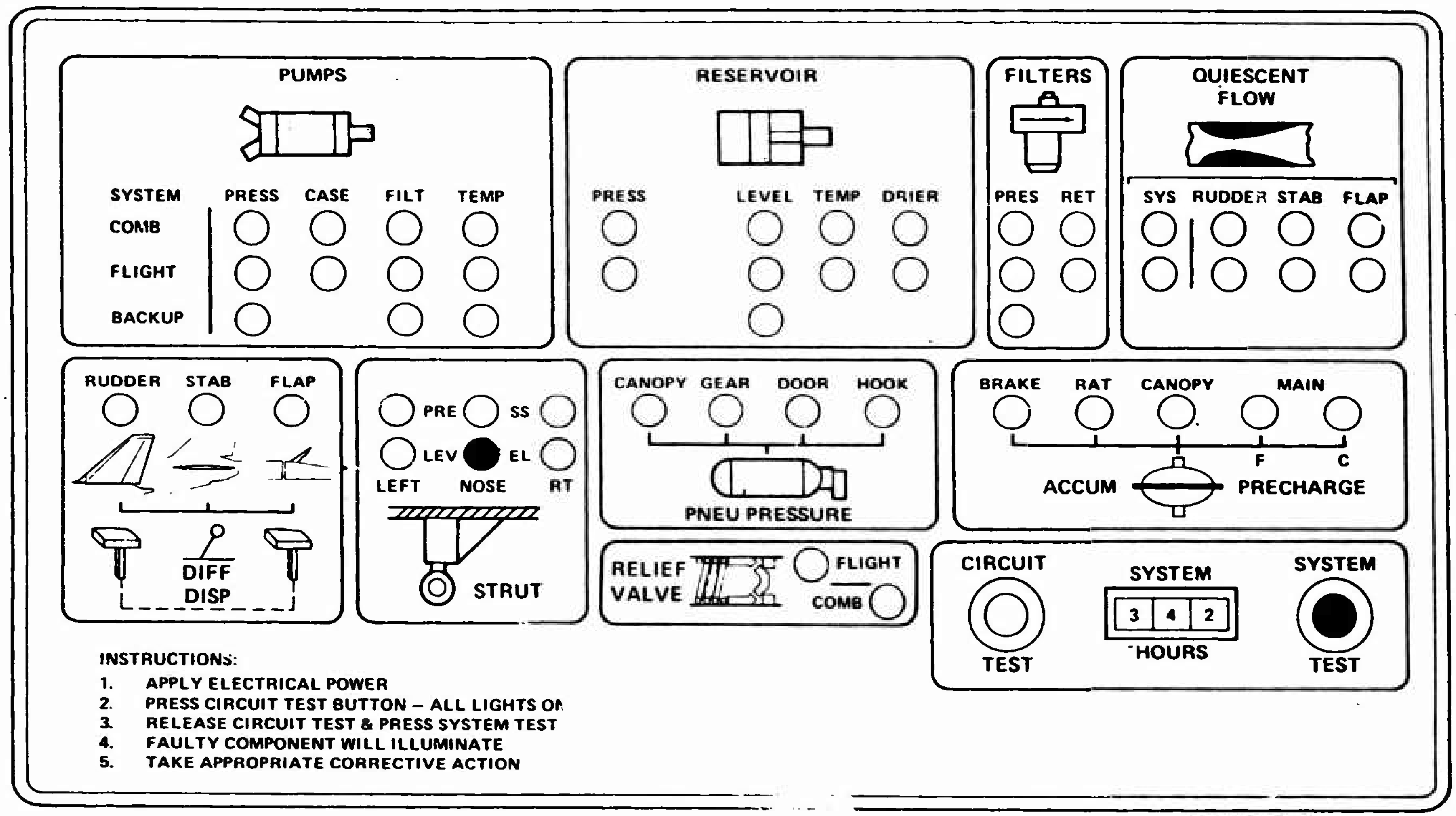
Panel Readout
- Access door opened
- System test button depressed
- Indicates faulty combined hydraulic pump - high case flow and fluid over-temperature.

Figure 64. HYCOS display (readout).



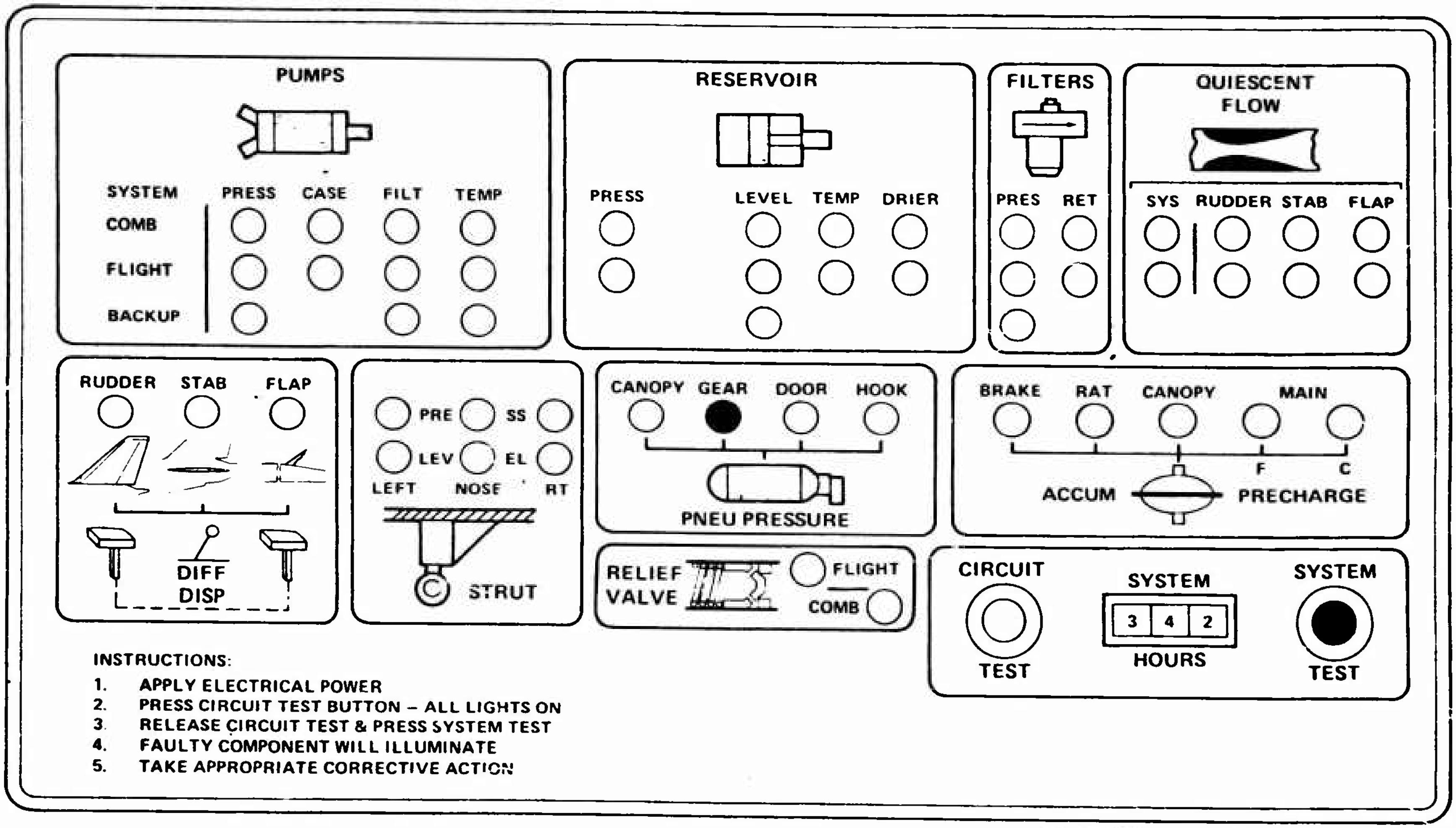
Panel Readout
- Engine pumps turning
- Access door opened
- System test button depressed
- Indicates failed hydraulic pump.

Figure 65. HYCOS display (readout).



Panel Readout
- Access door opened
- System test button depressed
- Nose strut fluid level low.

Figure 66. HYCOS display (readout).



Panel Readout

- Access door opened
- System test button depressed
- Emergency gear pneumatic bottle pressure low.

Figure 67. HYCOS display (readout).

TABLE 14. HYCOS SEQUENCE OF OPERATION

STEP	Hycos Logic	Signal	Condition
1	Supply electrical power to vehicle		
2	Open access panel – actuates circuit	Activates circuit to flow sensors	System ready for interrogation
3	Press and hold circuit test button		
	(A) All LED's illuminate	All LED illuminate	System circuits complete
	(B) All LED's do not illuminate faulty circuit or LED repair or replace as required	All LED do not illuminate	LED or circuit faulty
4	Press and hold system test button		
	(A) Read static sensors		
	1 Filters (ΔP)	Pressure return or case filter Indication	Indicates contaminated system Potential failure mode or lack of servicing Replace or repair as required
	2 Strut pressure & level	Low level leaking strut	Possible dammage to structure of due to hard landing
	3 Pneumatic bottle pressure	Low pressure	Loss or emergency gear blowdown backup
	4 Accumulator precharge	Brake Accumulator	Loss of reserve braking
		R A T Accumulator	Loss of emergency power
	5 Pump case flow temperature	Pump case temp illuminated	Low fluid level – potential pump failure
	6 Dessicant drier condition	Readout changes from pale blue to pink	Saturated bleed air moving to reservoir
	7 Relief valve (overtemp)	Relief valve LED illuminates	Indicates leaky relief valve
	8 Pump case flow	Pump case flow LED illuminates	Indicates potential pump failure if temperature & case filter LED illuminates replace pump
5	Start engines (no control input) press and hold system test button		
	(A) Read dynamic sensors		
	1 Pressures	Illuminated LED indicates low system or reservoir pressure	Check system relief valve or pneumatic reservoir pressure reducer
	2 Reservoir		
	● Air	Air LED illuminates	Bleed air from system
	● Level	Level LED illuminates	Add MIL H 5606 to reservoir & bleed, as necessary
	3 Quiescent flow		
	● System	System quiescent flow LED illuminates	Check flight control actuators quiescent flow LED If none illuminated, check system components for bypass
	● Flight control actuators	Flight control actuator LED	Recycle & pressurize system – If LED illuminates Replace actuator
	4 Differential displacement	differential displacement LED illuminates	Check input output linkage
	5 System hours		
6	If panel indicates out of limit readout, shut down engines		
	(A) Verify questionable component with a mechanical readout (as applicable)		
	(B) Replace or service out on tolerance component utilize system hours reading on panel for recording time log on replaced or serviced part		
7	Manually reset mechanical indicators after corrective action has been taken		
8	Repeat HYCOS checkout to verify that condition has been corrected (Q/A function)		
9	Close access panel		

3-CONCLUSIONS

- The benefits of HYCOS in a typical aircraft hydraulic system will
  - Result in lower scheduled maintenance
  - Reduce logistic requirements
  - Detect failures on out of tolerance component/subsystems
  - Detect incipient failure modes
  - Maximize component utilization
  - Lower skill requirements
  - Provide quality assurance verification
  - Increase component operating time and replacement cycle.
- The six months study effort has established normal and abnormal operating parameters of critical-for-flight components within a sophisticated aircraft hydraulic system such as found on an A-6 aircraft. Similar types of components on the F-14, EA-6B, and E-2C were also considered during this period.
- Monitoring criteria or components investigated and their respective subsystem were established. These were based on actual operating and overhaul limits.
- Sensor and readout devices were explored to monitor the component parameters established. These can vary from vehicle model to vehicle model. Some sensors readily adapt themselves to an existing piece of hardware or component while others must be added to the circuit.
- Propose system integration was made with respect to a typical aircraft installation.
- The HYCOS system lends itself to adaptation for the new lightweight hydraulic system (8000 psi) and components within the system can be adapted to operate under this pressure.
- Proposed sensors were configuration finalized in the following areas:
  - Pumps
  - Pneumatic Bottles
  - Filters
  - Display

- Reservoir level sensing utilizing a microprocessor is an effective way of handling multiple variable inputs.
- The R. L. S. microprocessor can be programmed for:
  - Fluid temperature compensation
  - Entrained air
  - System compliance
  - System accumulator.
- Sensors which require additional development effort are:
  - Shock strut fluid level determination
  - Accumulator piston position
  - Reservoir level sensing using simple logic circuits
  - Contaminant rate buildup in pump case drain filter.

4-RECOMMENDATIONS

Based on the results of Phase I HYCOS effort, the following recommendations are proposed:

- Continue with Phase II system development, system integration, and flight test.
- Select a test vehicle where a prototype HYCOS System could be integrated into one of the two hydraulic systems.
- Utilize an A-6E attack aircraft for flight tests and an F-14A hydraulic simulator for HYCOS subsystem test and integration.
- Permit the use of bailed A-6 aircraft with a piggyback HYCOS system installed for minimal cost impact. Monitor the effectiveness of the system for a period of at least six months.
- The proposed monitored system would be the combined (utility) system where more components requiring sensing are available.
- Conduct independent study on remote level and pressure sensing such as in the shock strut and dash pot.
- Consider independent study on more application of fiber optics as applicable to hydraulic systems.
- Develop advanced simple logic circuits associated with failure detection, isolation, and trending.

5-REFERENCES

1. MIL-H-5440 Hydraulic Systems, Aircraft, Types I and II, Design and Installation Requirements for

2. MIL-H-8775C Hydraulic System Components, Aircraft and Missiles, General Specification for

3. MIL-F-8815 Filter and Filter Elements, Fluid Pressure, Hydraulic, Line, 15 Micron Absolute, Type II Systems.

4. Keller, George, Hydraulic System Analysis Industrial Publishing Company, Cleveland, Ohio

5. MIL-R-8931 Reservoirs: Aircraft and Missiles, Hydraulic Separated Type

6. V. L., Streeter, Hydraulic Transients McGraw Hill 1967

7. Fluid Meters Their Theory and Application ASME 5th Edition 1959

8. Aerospace Fluid Component Designers Handbook: Air Force Rocket Propulsion Labs RPL-TDR-6425

9. Fainman, Morton Z., Halogenated Solvents and Corrosion in Dynamic Systems, MFZ Associates, Los Angeles, Calif. (ASLE Reprint 74 AM-5A-2).

10. Felsen, Marvin J., and Gilbert, William, Analysis of Hydraulic Fluid for Chlorine-Containing Contaminants, Lockheed - California Company, Burbank, California (ASLE Volume 30: pages 506-509)

11. International Critical Tables

12. SAE AIR 1416 Phosphate Ester Aircraft Hydraulic Fluid Contamination with Chlorine Containing Compounds

13. MIL-H-5606 Hydraulic Fluid, Petroleum Base, Aircraft Missile and Ordinance.

14. MIL-H-83282 Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft

15. Siegmund, Dr. Walter P., Fiber Optics, Principals, Properties & Design Considerations

Companies Contacted or Participating in HYCOS Effort

1. Millipore Corporation
   Bedford, Massachusetts 01730

2. Aircraft Porous Media
   Glen Cove, New York 11592

3. Arkwin Industries Inc.
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4. Temposonics Inc.
   Plainview, New York 11803

5. Beckman Instruments
   Fullerton, California 92634

6. Pacific Scientific
   HIACC Division
   Montclair, California 91763

7. American Optical Corporation
   South Bridge, Massachusetts 01550

8. EI Dupont Denemours & Company
   Wilmington, Delaware 19898

9. Abex Corporation
   Oxnard, California 93003

10. New York Air Brake Company
    Watertown, New York 13601

11. Franklin Institute Research Labs
    Philadelphia, Pennsylvania

12. Crane-Hydro Aire Division
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13. Dayton T. Brown
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16. Ikor Incorporated
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17. Hycal Engineering
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18. Esso Research Labs
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19. National Semi-Conductor Corporation
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20. Siemens Corporation
Scottsdale, Arizona 85252

21. Dialight
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22. Environment One Corporation
Schenectady, New York 12309

23. R.C.A. Service Company
Springfield, Virginia 22151

24. Valtec-Electro Fiber Optics Division
West Boylston, Massachusetts 01503